ASEA GENERATORS

DESCRIPTION
PUBLISHED BY
ALLMÄNNA
SVENSKA
ELEKTRISKA
A.-B.

GÖTEBORGS LITOGRAFISKA AKTIEBOLAG
GÖTEBORG 1920

INTRODUCTION.

THIRTY years have elapsed since the epoch-making discovery of the three-phase system, which system was evolved independently in Sweden at precisely the same time as in other countries. To commemorate the achievements of Sweden in this respect, and as an illustration of its electrical and engineering progress we have collected a few short descriptive articles dealing with some of the most interesting of our installations; in nearly every case the plants in question are driven by slow speed water turbines and indicate the general design and construction of alternating current machines built in our factories.

We take this opportunity of recording our appreciation to our numerous friends and customers, for their consideration shown in placing orders, which have made it possible for us to develop machinery competitive with the largest firms in the world, and to demonstrate the good qualities of Swedish engineering practice and workmanship.

Västerås, Sweden, September 1919.

ALLMÄNNA SVENSKA
ELEKTRISKA AKTIEBOLAGET

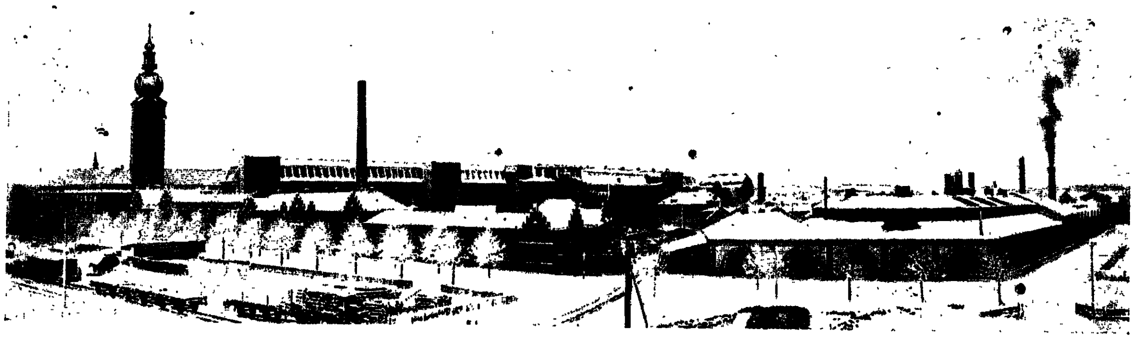


Fig. 1. View of Asea's old and new Office Buildings with Mimer Shops and foundries.

HISTORY

WHEN THE TECHNICAL ASPECTS AND POSSIBILITIES OF UTILISING alternating current commenced to attract general interest and attention in the early eighties, Asea was one of the first companies to give close and careful study to the numerous technical problems which then arose. The paramount reason for such intense interest was the fact that their then Chief Engineer — Mr. Jonas Wenström — (whose discoveries some ten years before and subsequent development of D. C. machinery had been chiefly instrumental in founding the Asea company) now started to perfect his previous inventions relating to alternating current machinery, systems and appliances. As a direct outcome of this pioneer work, a patent was granted in 1890 entitled "Arrangements for transforming and distributing energy by means of 3 alternating currents of the same frequency and with a phase difference of a third of a cycle", which covered a complete system of three-phase power transmission. Asea who had taken over the patents, built experimental machines during the summer of the same year, consisting of a self-excited generator, transformer and motor.

Numerous experiments were made with this equipment and although on the whole expectations were realised, it was conclusively demonstrated and recognised that desirable and necessary improvements could be made —parti-

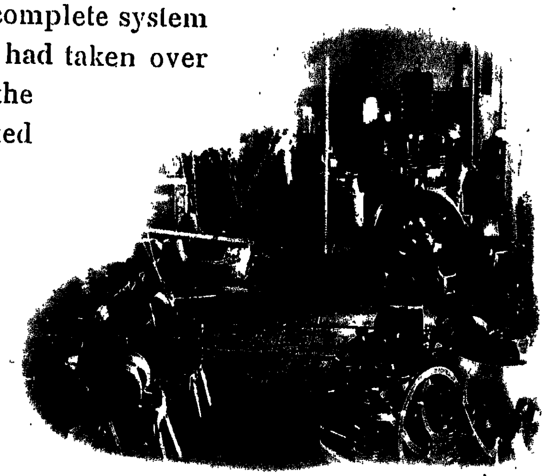


Fig. 2. Interior of Asea's works in 1895.

cularly in the motor — before the theoretical considerations were turned to practical use. About 18 months later Wenström, with the assistance of E. Danielson in his experiments, produced such a satisfactory motor that at the beginning of 1893 Asea entered into a contract to build the first Electric Power Transmission plant in Sweden

A. Lindström.

J. Wenström.

E. Danielson.

on the Wenström system. This installation was completed by the end of the year, and was for Sweden what the well known Lauffen installation was for the Continent. The plant consisted of a 300 horse power generating station at Hellsjön, 15 kilometers of transmission line working at a pressure of 9500 volts, transformers, and a large motor equipment at Grängesberg; this installation, which is in service at the present time, has proved highly successful. The eminently satisfactory manner in which the whole plant operated attracted considerable attention, resulting in numerous requests for similar installations: as a direct consequence, during the next few years, Asea's production of A. C. machinery reached proportions as large as the output of D. C. machinery. One reason for this rapid advancement was the superiority of the three-phase system, this being recognized as particularly applicable to Swedish topographical conditions, and it was known even in those days as the most efficient method of transmitting power.

For the rapid development and advances made in the practical application of this new

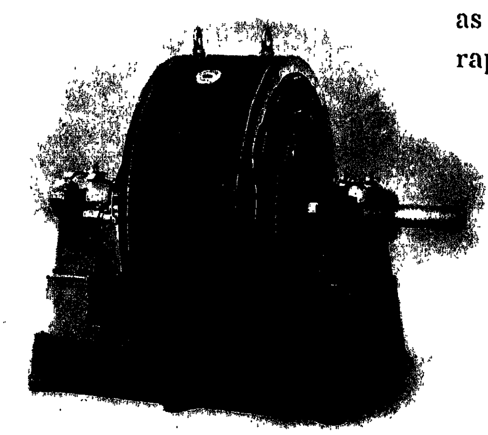


Fig. 4. Three-phase generator type VA.

science credit must also be given to the engineers, who — after Mr Wenström's death in 1893 — were responsible for the technical work of Asea; particularly Mr E. Danielson and Mr A. Lindström, who so ably followed and worthily upheld the pioneer work of Mr Wenström. During the following years these engineers and their colleagues worked hard to perfect the system, and laid the foundation for the statement made at Asea's twentyfifth Anniversary in 1908 that: — "Without exaggeration it could be said the history and progress of the 3-phase system was indistinguishably linked with the developement and progress of Asea." During these early days the output of the works tended to develop more and more towards the construction of A. C. motors, generators and transformers; as a result, the D. C. machinery, for which Asea had in the first instance been promoted and organised, no longer held the premier position; nevertheless considerable progress was maintained with improvements to D. C. equipments, and developments also took place in this direction concurrently with the production of A. C. plants. Naturally the bulk of the orders received covered motors and transformers but the construction and supply of generators was by no means small. The generators being built in larger units, required bigger machine tools and more shop-space for handling, erection and testing; moreover greater interest was centred upon the larger generators particularly in the early days. The most interesting feature during the last ten years has been the evolution of large A. C. generators for power transmission, their large size having been emphasized and exploited, whilst advances in motor, transformer and switch gear design and construction have not attracted as much attention, although in certain directions their advancement and improvement has more than kept pace with the development of generators. When thinking in a broad way of Asea's output, the first thing that strikes one forcibly is the number of generators of large capacity that have been built by the firm.

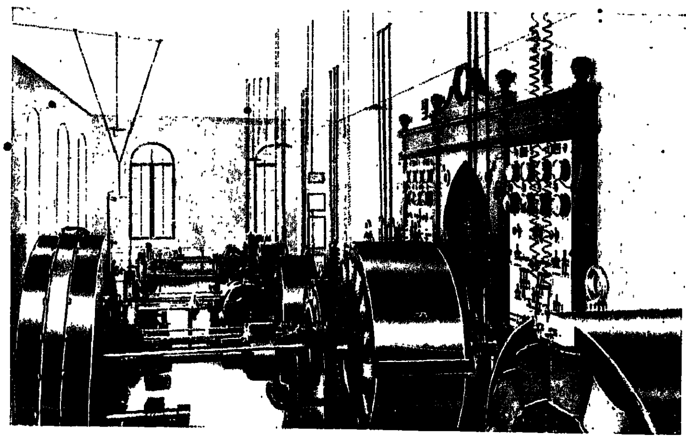


Fig. 5. Hellsjön Power Station. 3-three-phase generators 70 KVA, 600 r. p. m. 70 cycles, and 3-110 KVA sets.

With the exception of the experimental generator referred to above, the first A. C. machines supplied by Asea were built for Hellsjön

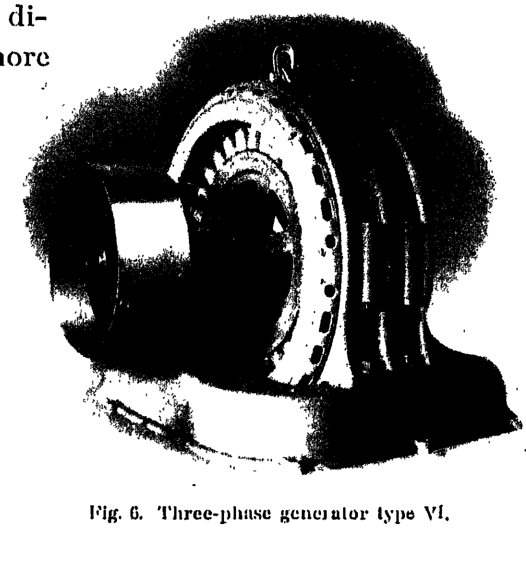


Fig. 6. Three-phase generator type VI.

Power station; these had a continuous rating of 70 KVA at 600 r. p. m. with 70 cycles and 150 volts. They were horizontal machines with rotating armatures and two pedestal bearings; the stationary field ring of cast iron had 14 poles, the weight of copper on the field coils was 1000 lbs. and that on the armature 110 lbs; the whole machine weighed 3 tons corresponding to approximately 95 lbs. per KVA. This, to modern engineers, appears to be a disproportionate figure, but it must be borne in mind that much of the material now in every day use, was at that time absolutely unobtainable, whilst accurate scientific knowledge did not exist as to the properties of these materials — nor had the art of calculating, from the meagre data available, advanced to the position it now occupies. Full credit must therefore be given to those engineers for their tenacity and resolution, resulting in the production of electrical machinery which formed the foundations upon which our present scientific knowledge for electrical calculations are largely based.

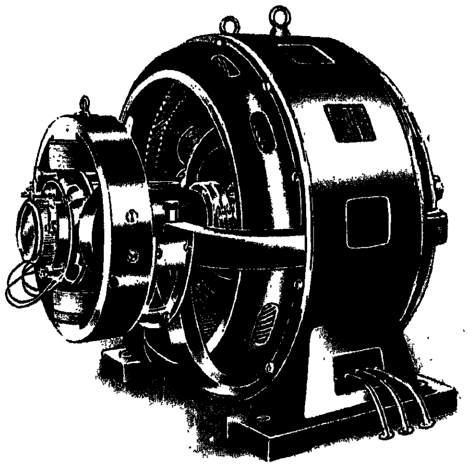


Fig. 7. Three-phase generator type VMC—VAC with direct coupled exciter.

Concurrently, with the original generators, others were taken in hand, and immediately the result of the successful working of the Grängesberg installation became known, requests were received for similar plants but of varying capacities; consequently Asea decided to get out a series of generators with standard frames. This range of machines was built in sizes from 3 to 125 KVA at a speed of about 600 r. p. m. and 50 cycles; they all had stationary fields and rotating armatures similar to those first installed at Hellsjön, but they were designed on more efficient lines in order to secure better results from a given weight of iron and copper. This range of machines was designated VQ, VO, VM, but

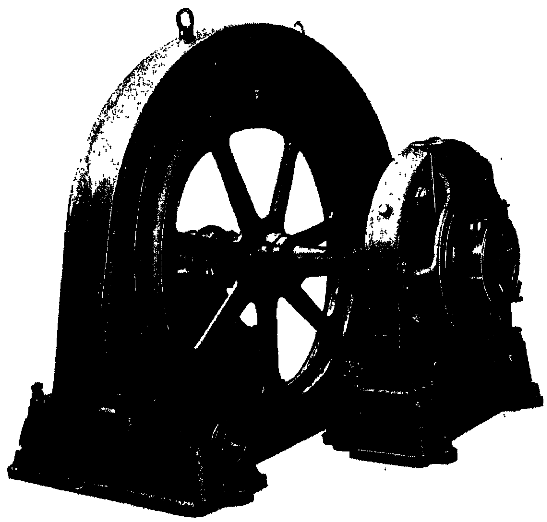


Fig. 8. Three-phase generator 212 KVA for Küschtümsk, Russia.

Fig. 9. "Brides Veil" Fall.

beyond these series two larger types were also produced; one with an output of 185 KVA at 375 r. p. m., the other with an output of 280 KVA at 300 r. p. m., 50 cycles. Owing to Mr Danielson's skill and foresight when working out these designs, this pattern was manufactured as a perfectly standard machine for many years and existed from 1892 until 1906 when the last machine of that type was manufactured. All these machines were run at comparatively high speeds, the lowest at 300 r. p. m. and highest at 1000 r. p. m.; the normal frequency was between the limits of 50 and 60 cycles but as the importance of fixing a standard frequency was not recognized until the middle nineties, it was common practice to change the frequency so as to use the same frame — in other words carcase and r. p. m. of prime mover, were factors which determined the speed and consequently the frequency. It naturally followed that different installations very seldom had the same periodicity, but generally speaking it was somewhere between the limits of 50 and 70 cycles; in a few cases machines 45.3 and 46.6 cycles were built but the manufacturers and users soon came to the conclusion that it was necessary to adopt some standard. After much discussion it was decided in 1896, at the "Svenska Teknologföreningen", that 50 cycles should be adopted, more particularly as at that time continental engineers had also accepted 50 cycles as a standard. From this time all new machines were built for the standard periodicity, except in cases were extensions to existing power plants were involved.

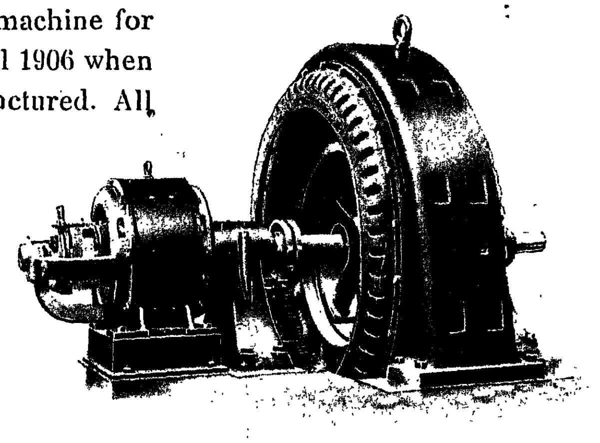


Fig. 10. Three-phase generator type G, with direct coupled exciter.

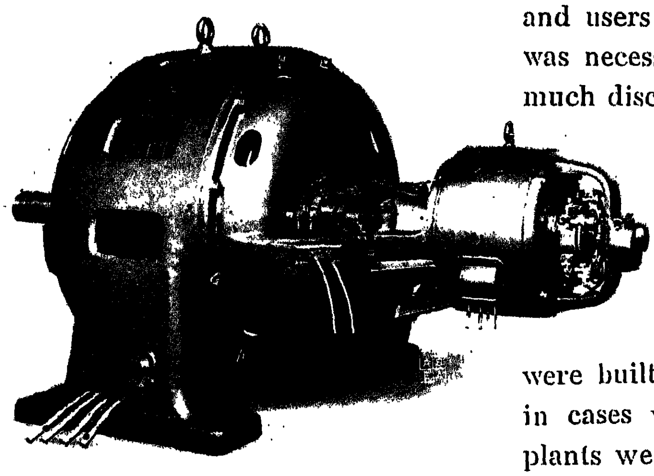


Fig. 11. Three-phase generator type G, with direct coupled exciter.

About the same time the design of large slow speed machines was undertaken but these were not standardized to such a degree as the smaller ones, being only built as required. They were however later on grouped and classified in two sections, one known as the VA class covering four sizes up to 100 KVA with speeds between 131 and

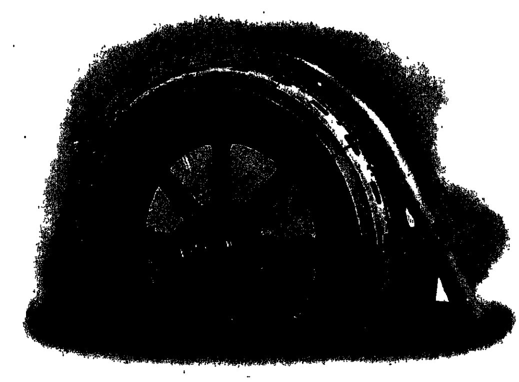


Fig. 12. Three-phase generator type V, 225 KVA, 400 volts, 125 r. p. m., 50 cycles for Lahtis, Finland.

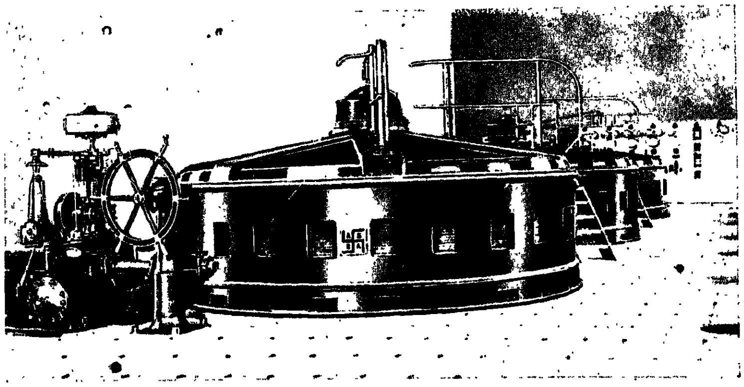


Fig. 13. Cobalt power station, Canada. 3 three-phase generators 875 KVA, 11000 volts, 150 r. p. m., 60 cycles.

300 r. p. m., the other as VC class. This latter comprised five types up to a maximum of about 600 KVA at speeds ranging from 70 to 375 r. p. m., or for very exceptional cases up to 600 r. p. m. These sizes were retained up to the year 1900 when they were regrouped, the first group covering machines up to 145 KVA and the second extending up to 800 KVA, the frequency being retained at 50 cycles. All these machines were constructed with stationary armatures similar to present practice, the armature core being built up of paper insulated sheet iron in sections, separated by distance pieces to permit air circulation. These cores were held in a substantial cast iron stator casing by means of forged steel rings. The rotating field construction was modified on various occasions, the first design being known as "the claw" type, but this was soon abandoned on account of its poor magnetic qualities. The next pattern had laminated pole shoes and core of iron stampings but suffered from various drawbacks; consequently the design was again changed, and what is practically the present day construction decided upon, comprising forged magnet cores secured to a cast iron flywheel. Nearly all these machines were of the horizontal pattern with two pedestal bearings, but to meet special

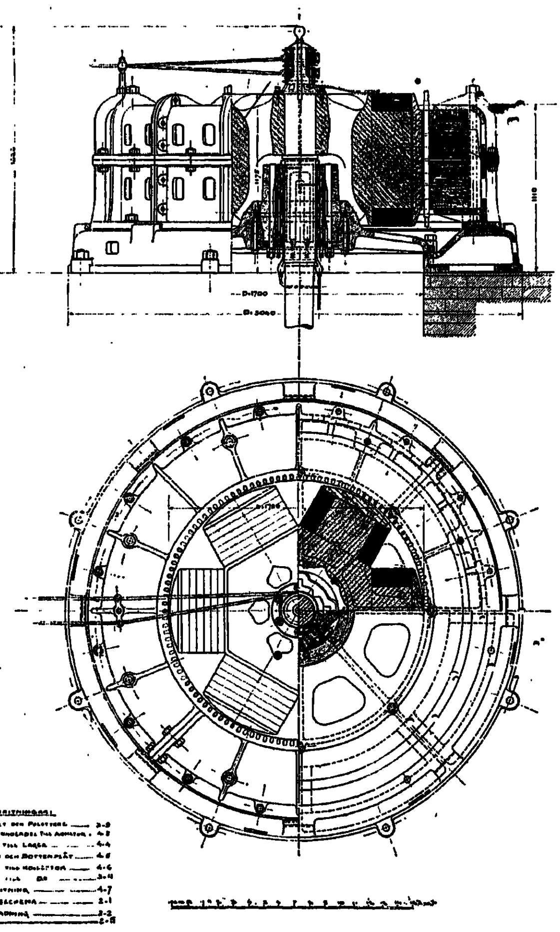


Fig. 14. Single-phase generator for De Laval's experimental Station at Trollhättan.

Fig. 15. Old waterwheel at Rydahl.

requirements vertical type generators were also made in exceptional cases. A considerable number of these machines were built but had eventually to give way to improved designs and more modern construction; the VA class was therefore discontinued in 1906 but the manufacture of the VC generators continued until 1911.

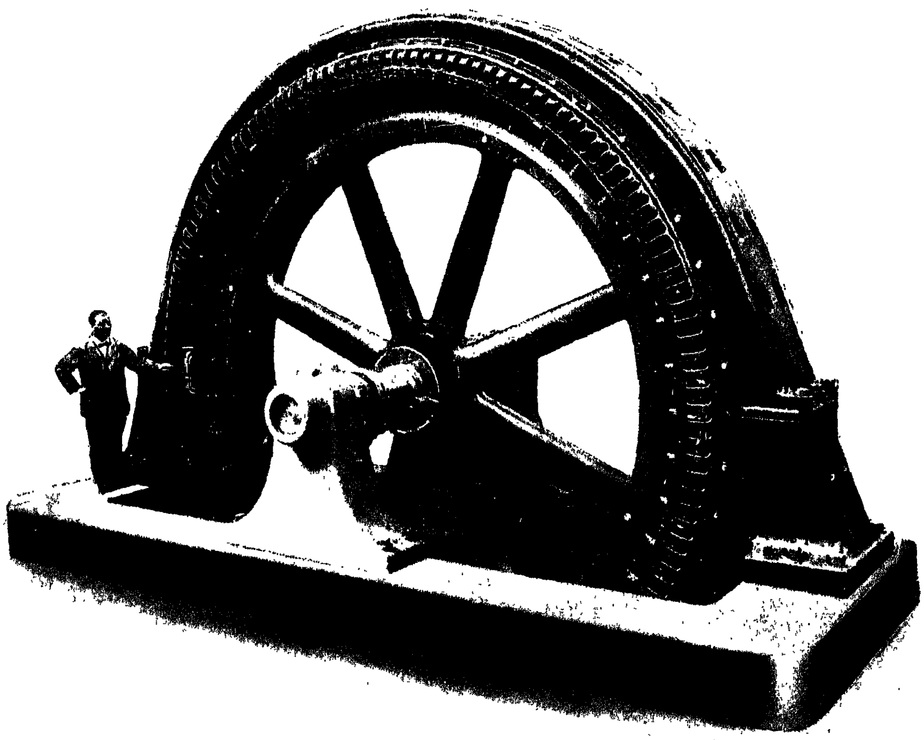


Fig. 16. Three-phase generator type G, 3750 KVA, 2300 volts, 163 r. p. m., 60 cycles for Eddy Co., Hull, Quebec, Canada.

In 1901, after five years experience covering large and medium sized machines with rotating fields, it was decided to extend this construction to the smaller machines. These series (designated VMB—VAB) included five standard types, in sizes ranging from 8 to 225 KVA at 375 to 1000 r. p. m, 50 cycles: based on the extensive experience previously gained this new type proved to be well constructed in every way, even according to modern ideas. The machines were arranged either for direct coupling to a prime mover or for belt drive, in the latter case the substantial bedplate was mounted on slide rails.

All these generators of the horizontal type were, as stated above, built with rotating fields and provided with two bearings, of the self-oiling type, mounted on a common bedplate. For self-excited machines one of the bearing pedestals had a bracket attached to support the exciter; about 30 machines of this type were built during the next few

Fig. 17. The new power house at Rydahl, Sweden.

years; but they were soon discarded and replaced by a more efficient and up to date design.

This series, consisting of two types (VMC and VAC), was put on the market in 1904, the sizes ranging from 25 to 550 KVA with speeds from 375 to 1000 r. p. m.

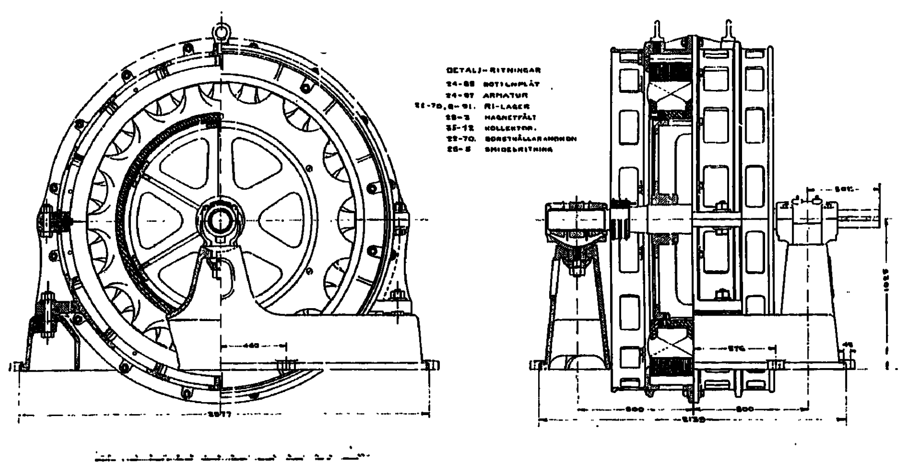


Fig. 18. Three-phase generator for Rydahl with "claw type" field.

and frequency of 50 cycles. The design was similar to the old type for direct or belt drive, with the exception that instead of pedestal bearings they had end shields with three arms cast to form a support for the bearings and protect the stator windings — the bearings were lubricated by oil rings as in the former series.

These machines were frequently arranged with an exciter mounted on a bracket on the end-shields, in which case the generator shaft was extended for the exciter which then required no bearings (see Fig. 7). When an independently driven exciter was used it was mounted on a separate bedplate and driven from the generator shaft by means of a flexible belt coupling.

Asea had by these series of generators produced strictly standard and modern type machines, with all details fully worked out and parts made to gauges and templates, so that a line of generators and motors could be manufactured in mass, thus a stock of machines could always be kept on hand.

Two years later, in 1906, a newly designed series of large machines was introduced, which were used for similar work as series VC, which latter type was still being made; this series together with the new, was called series V with an index number indicating the capacity and arrangement of the machine and fulfilled all requirements; the new design completely met the demand for slow speed machines and those of greater capacity than

Fig. 19. Three-phase generator type G with direct coupled exciter.

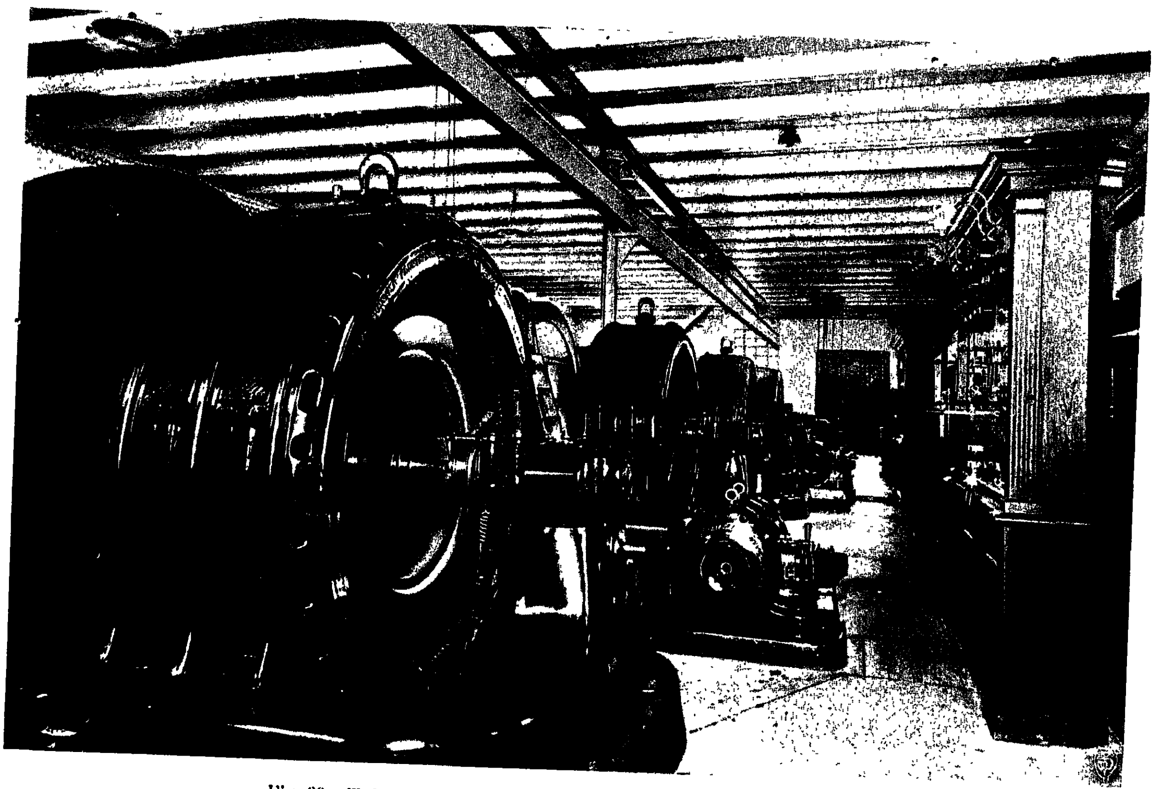


Fig. 20. Trångfors power station (A.-B. Svenska Metallverken).

the old VC series. These machines were designed on the same lines as the more recent types of the old series *i. e.* they had the armature winding in the stator and rotating field.

In the old series, pedestal bearings with and without water cooling had been used, but on the later machines ball or roller bearings were adopted — these were mounted in a strong spider fastened to the stator frame, and thrust bearings were used to prevent endplay. The latest VC group of machines and also types VMC, VAC and V secured a wide market and many installations for Asea, not only in Sweden, but also in Norway, Denmark and Finland, showing the reputation Asea had gained for their products — even far distant countries readily purchased Asea's machines as indicated by their many installations in Russia and still more in Canada, where a great number of power stations bear Asea's well known trademark.

Owing to developments which took place in the industrial world in 1907 changes were made in Asea's productions, new materials and improved designs were put on the market although the last mentioned machines were then the best the technical world was

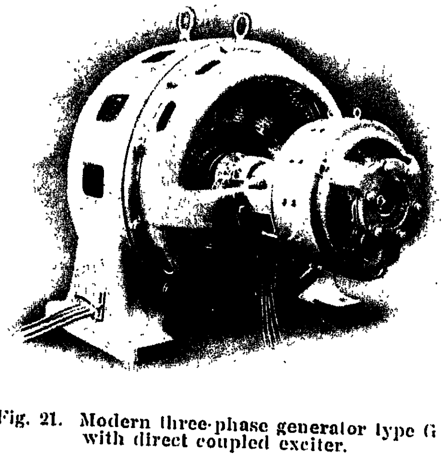


Fig. 21. Modern three-phase generator type G with direct coupled exciter.

producing and it was only then possible to make further improvements owing to these new advances and better constructive materials.

Therefore, in 1908, a new series of generators with end shields was commenced, called "Series G" with index numbers, ranging from 125 to 650 KVA at 250 to 600 r. p. m. and frequency of 50 cycles.

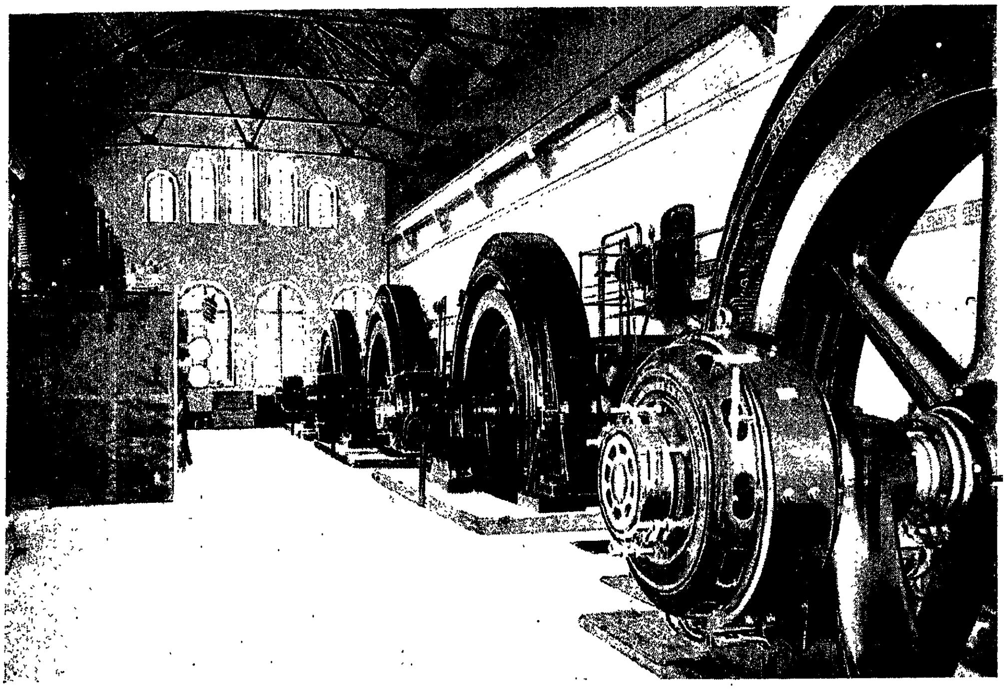


Fig. 22. Skärblacka Company's power station. 5 three-phase generators, total capacity 4260 KVA, 800 volts, 50 cycles.

These machines were also designed for 25 cycles and were made in sizes from 200 to 500 KVA at 300 to 500 r. p. m. At the same time another type was evolved, with pedestal bearings, but of greater capacity. This was also called "series G" with an index and was so proportioned that the smallest of these machines with the same r. p. m. was a step in advance of the largest of the end shield type. These large "G" machines were designed for capacities from 250 to 4000 KVA at 75 to 500 r. p. m. and a frequency of 50 cycles; they were also designed for use on 25 cycle circuits. Finally a series of small high speed generators with end shields was introduced to take the place of series VMC and VAC; these machines, which in capacity were equivalent to the VMC and VAC series, were put on the market in 1910 and had about the same

Fig. 23. Trångfors power station, Västmanland.

appearance as the older machines but better use had been made of the material. This series consisted of 12 standard sizes from 25 to 250 KVA at 375 to 1000 r. p. m. and frequency of 50 cycles; when used with 25 cycles they were made for outputs of 25 to 200 KVA at 375 to 750 r. p. m.

Thus in 1911, three groups of machines were being built with varying capacities,

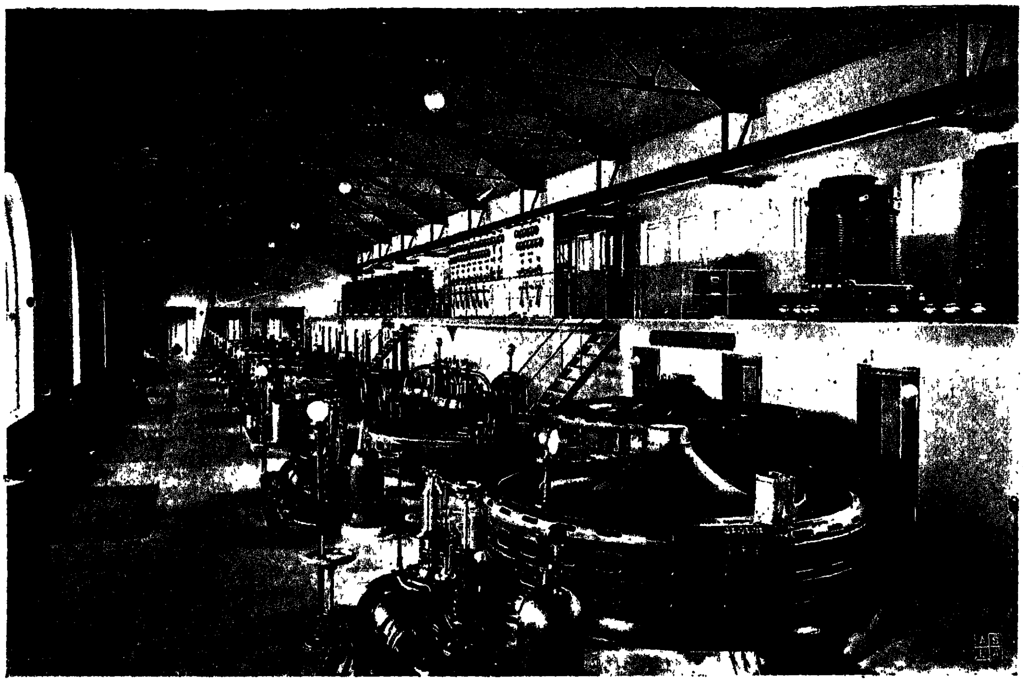


Fig. 24. Näs—Horndal Power station (Horndal Iron Works.). 11 vertical three-phase generators for 415 KVA, 660 volts, 214 r. p. m., 8 d:o for 575 KVA, 660 volts, 88 r. p. m., 50 cycles.

and were known as the "little G" series, which was the designation given to the end shield type mentioned previously, and the larger generators with pedestal bearings.

These machines were built as originally designed until 1915, when a change was made in the series; some of the smaller machines were then taken from the "large G" series, and included in the "little G" series, and some of the medium "large G" series were no longer manufactured. From this time onwards, Asea have only had two generator series — the extended "little G" series with about 20 sizes from 17.5 KVA at 1500 r. p. m. to 750 KVA at 750 r. p. m. and frequency of 50 cycles; the "large G" series including a great number of sizes ranging from 160 KVA at 375 r. p. m. to 7500 KVA at

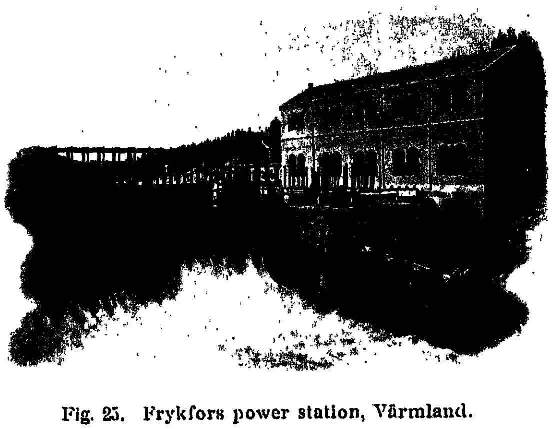


Fig. 25. Frykfors power station, Värmland.

150 r. p. m. with frequency of 50 cycles. Both these series have been improved and redesigned during the past few years upon the latest and most modern theory and the wide experience Asea's engineers have gained during the quarter century of their well known generator production.

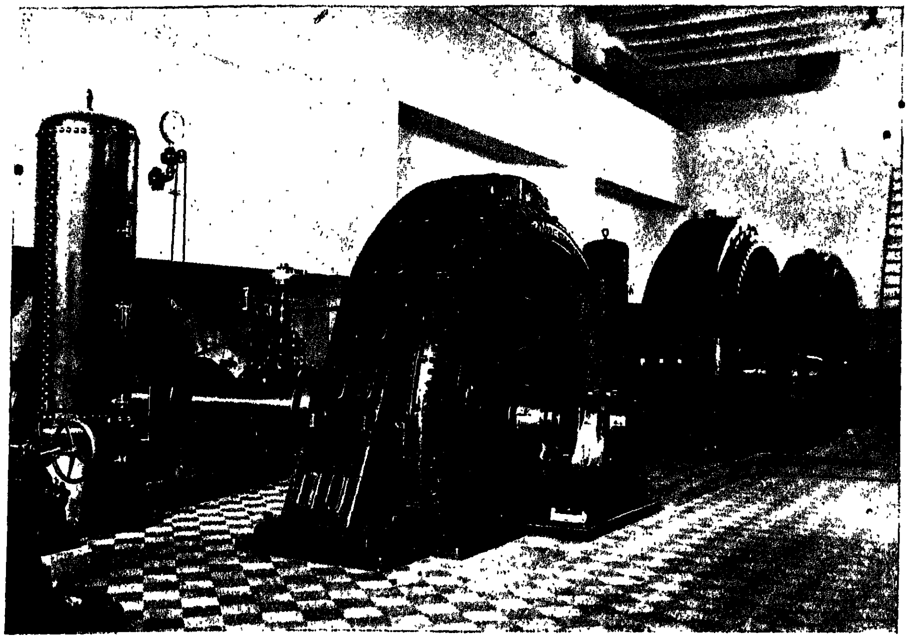


Fig. 26. Övre Knäred power station (South Swedish Power Co.).

All the little G series are standardised as far as the mechanical design is concerned; on the more popular sizes, the winding is also standardised and machines of this type are always kept in stock. In the large G series only mechanical parts such as stator frames, shafts, bearings and similar spares are kept in stock; there are however always a number of the smaller sizes of this series on hand.

Although a strict standardisation of machines is more or less limiting the market and putting a certain restriction on sizes, it has so many advantages from the manufacturers' point of view, that it more than compensates for these limitations; standardisation does not mean that the character of a machine is fixed once and for all, but rather that a certain construction must be adhered to in order to maintain fast and regular production; at the same time advantage is always taken of new inventions, better material and improved workshop appliances. In consequence of this, Asea's modern generators are always of the most up to date design and manufacture.

In this article we have tried to point out what has been accomplished during the past

Fig. 27. City of Västerås' turbine station.

25 years to develop both direct and belt driven generators; in addition to the machines already described a number of special machines have been built, which in size, construction, and special features have deviated from our standard machines, and as such, are worthy of special mention.

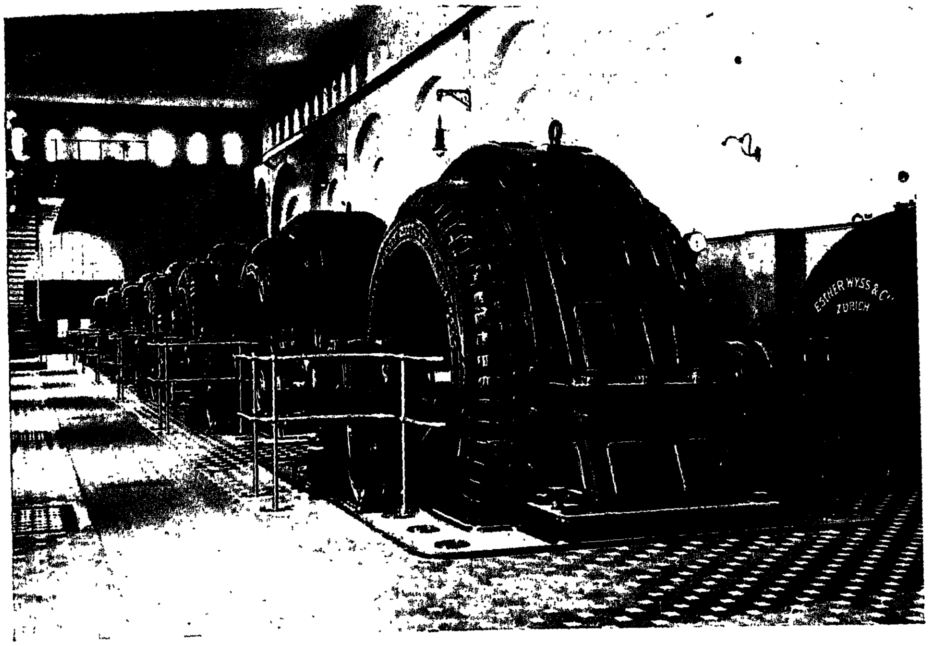


Fig. 28. Tysse power station, Norway.

In the following pages a description of the larger machines will be given individually, but a brief description of the smaller sizes will be found equally interesting. One of the first large machines built by Asea with special features, was a single phase vertical generator for Mr. De Laval's experimental station at Trollhättan in 1895. This generator was the largest that had been built in Sweden at that time, and as far as we are aware, the first with a rotating field with salient wound poles (Fig. 14 gives a good view of this construction). At this time, generators which have already been described with claw or zig-zag field windings were being built, one of the largest of this type is illustrated in Fig. 18 and was designed for an output of 260 KVA at 200 r. p. m. 3,460 volts, 46.5 cycles, but as already mentioned, very few of this type were built.

In place of this design larger and larger machines with salient pole fields were built; well worthy of mention amongst these, were the 6 — three-phase generators built for Trångfors power station in 1899. Designed for an output of 255 KVA at 250 r. p. m., 800 volts, 50 cycles they made

Fig. 29. City of Stockholm's power station at Värtan.

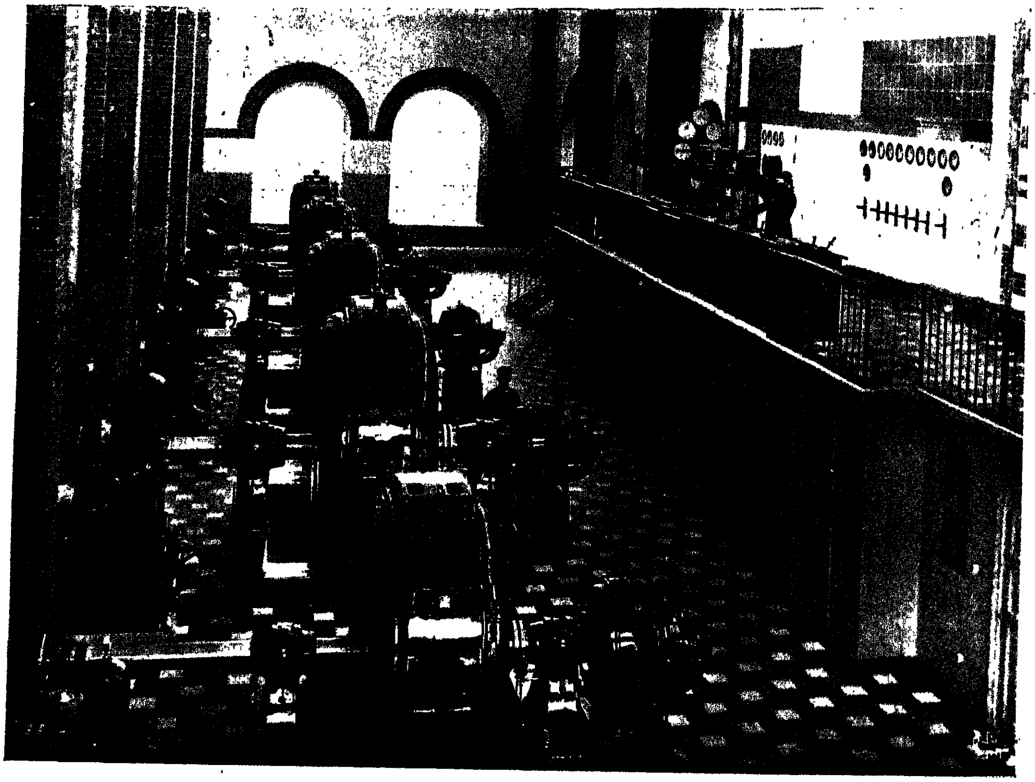


Fig. 30. The Power Plant of Ljungaverken (Stockholms Superfosfat A.-B.).

this station together with the remainder of the electrical equipment for the installation one of the largest contracts Asea had at that time undertaken. Five of these generators were sent direct to the Power Station, but the sixth was first sent to the Paris Exhibition in 1900, where it was duly considered and won the "Grand Prix".

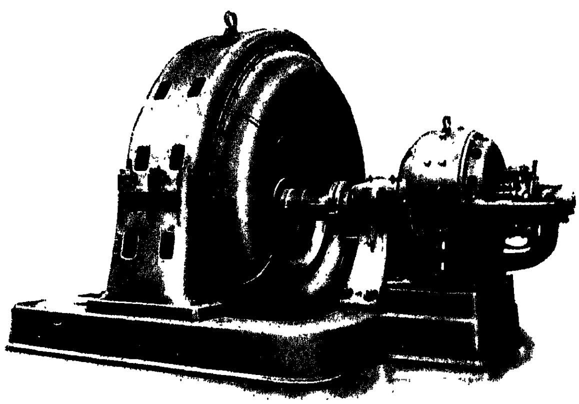


Fig. 31. Semi-enclosed generator for the Power Plant of Ljungaverken.

These machines, looked at from the present day standpoint, were not very big, but taking into consideration the factory facilities, tools and transport problems that had to be overcome, it was at that time quite an accomplishment.

Not long afterwards machines of much greater capacity were constructed, for example, those built for A/S Barbu in Norway in 1903—1904;

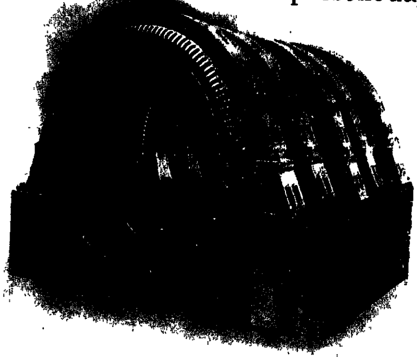


Fig. 32. Five stators for South Swedish Power Co.

these generators had a capacity of 1000 KVA at 125 r. p. m., 2000 volts, 50 cycles, armature winding on the stator, and rotating field; the pole pieces were of wrought iron on a cast iron wheel, the exciter was direct connected and mounted on one of the bearing pedestals of the alternator; perfectly open construction was used and in general design the machines were similar to modern sets.

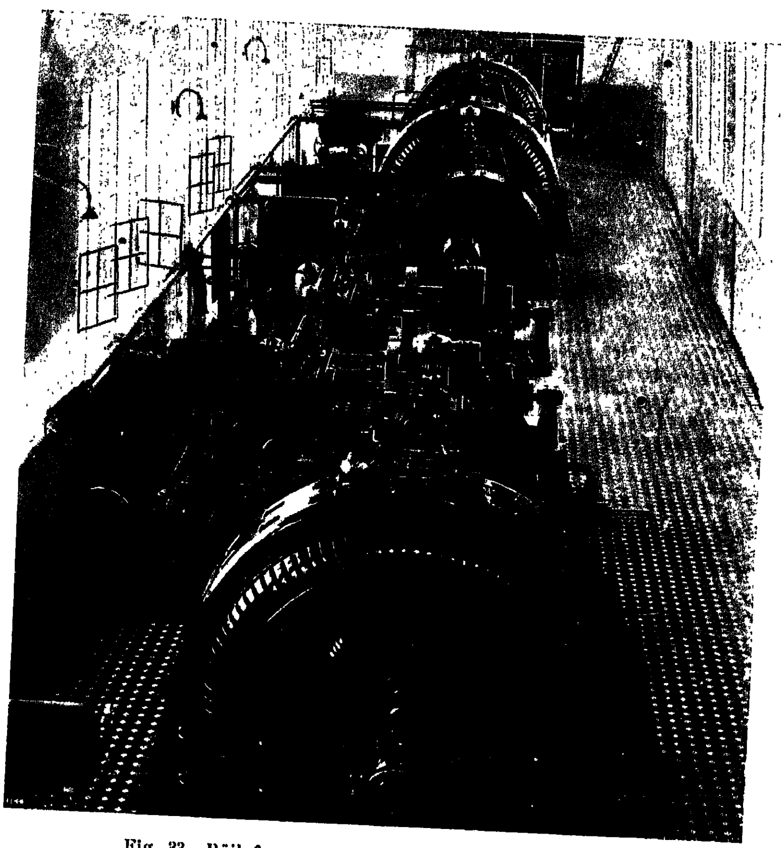


Fig. 33. Böjlefos power station (Arendals Fosse Co.).

During the same period a generator of the same size was built for Skärblacka Paper Mills (Fig. 22), with the difference that this machine was designed for 115 r. p. m. and 800 volts; also the machines for the Värtan Station of the Stockholm City Electricity Works, were under construction; these were for direct coupling to steam sets, and had a capacity of 1770 KVA, 100 r. p. m., 6500 volts, 25 cycles (Fig. 29).

By building these machines we entered a new field in our manufacturing career. New shops had been built with greater floor space, more powerful machine tools installed and better facilities were available for handling large work; so that by this time the construction of the large generators (most of which are discribed in detail in the following pages) known as "Asea giant generators" and which are amongst the largest in existence, could be commenced. Apart from these machines, however, others are well worthy of mention, as typical examples of the work we were undertaking at that time.

In 1907—9 we supplied the Tysse power station in Norway (Fig. 28) with 7 generators, each having a capacity of 4100 KVA at 375 r. p. m., 12000 volts, 25 cycles, at a power factor of 80 %; these machines of the open horizontal type with stationary armature and rotating field are direct connected to water turbines of the Pelton

Fig. 34. The "Bassalt" power station (South Swedish Power Co.).

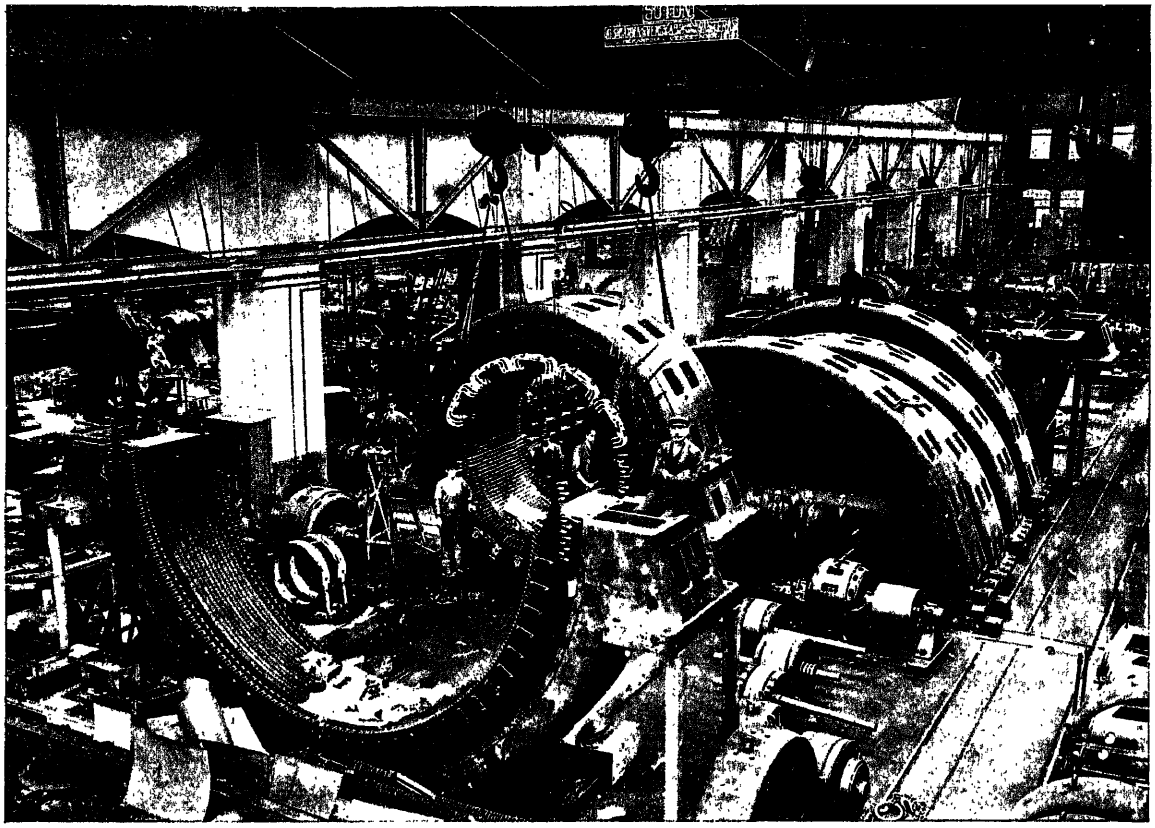


Fig. 35. Interior of Asea's shop for large machines.

type; the split stators have an almost modern appearance except for the style of air opening on the stator frame which reminds one of older types of machines.

In the same year the Sydsvenska Power Co. were supplied with no less than 8 three-phase generators for their power station at Lagan (Fig. 34); each of these machines has a capacity of 1420 KVA at 167 r. p. m., 5250 volts, 50 cycles at a power factor of 80 %. They are direct connected to water turbines and are of the standard open construction. A few years later Asea received an order for four more generators for this station, each rated at 3000 KVA for the same speed voltage and frequency as the original machines. Working conditions brought about by the 50 cycle power distribution system, were such that it was decided to design these machines for 65 % power factor and not, as on the older machines, for 80 % power factor. The generators are of entirely open type and like the older machines are direct connected to water turbines. The greater part of the 24000 KVA generated at this station is used in the cities of South Halland and West and South Skåne, but a

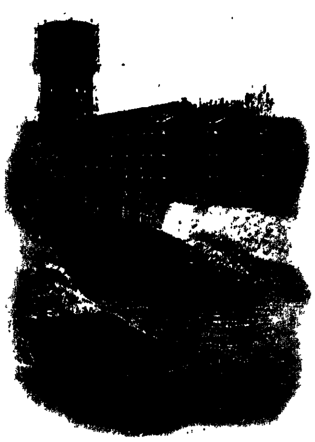


Fig. 36. Ljungaverken's power station.

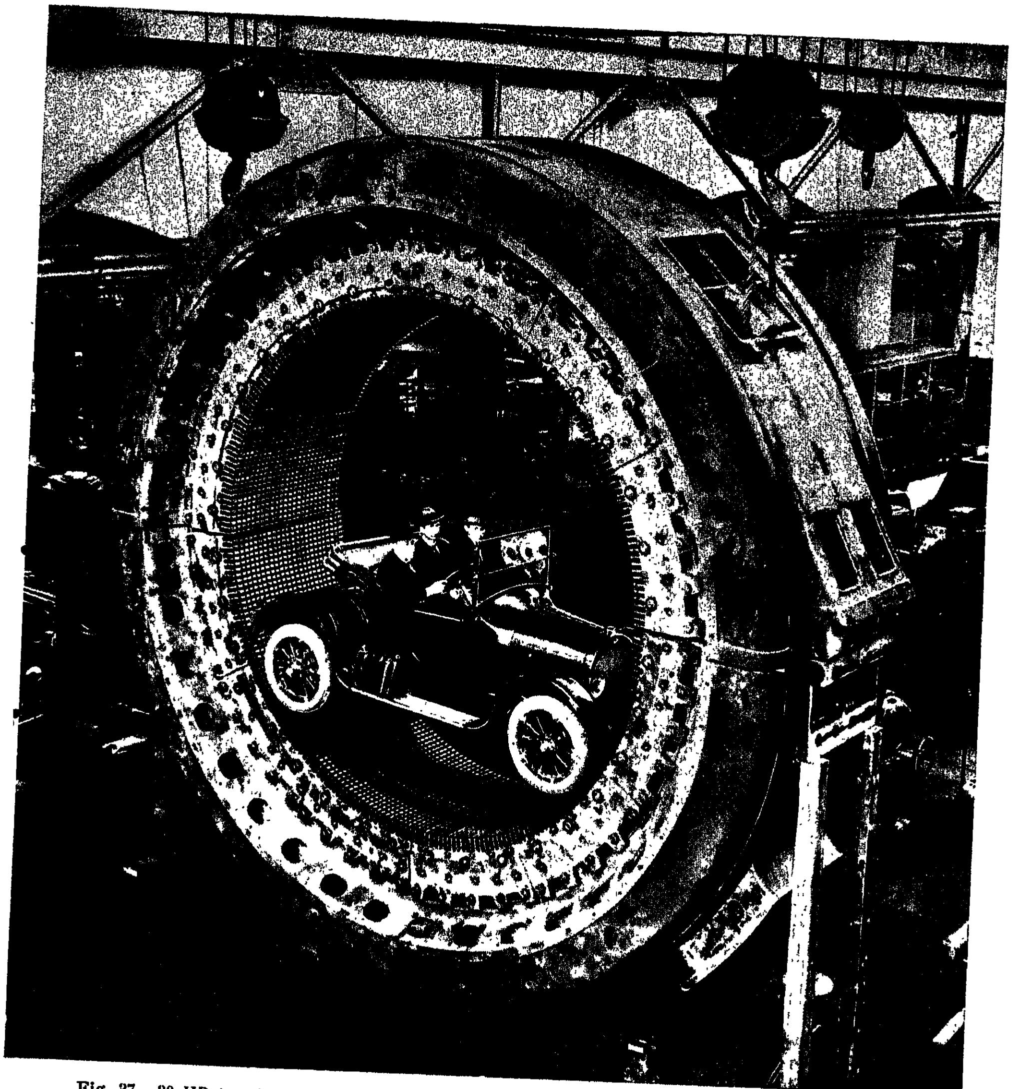


Fig. 37. 30 HP touring car in one of the twin-stators of Glomfjord generator having a capacity of 22000 KVA.

part is also transmitted to Denmark by means of a submarine cable through the Strait of Öresund between Helsingborg and Helsingör. The year 1910 formed an epoch in the building of machines; the period was entered at this date which might be called the period of large installations, commenced by such plants as Svælgfos developing 42000 KVA in 4 units, the installations already referred to at Tysse, Lagafallen, etc., also the large installations at Trollhättan and Rjukanfos (a description of which is given later) were planned and construction work commenced; together with Ljungaverken, which started operating in

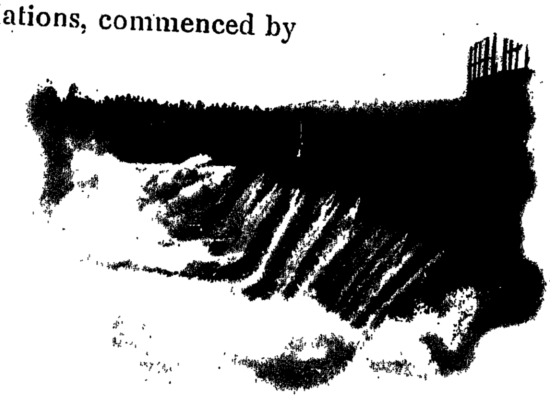


Fig. 38. Dam at Böjlefos.

1912 and consists of 4 generators, each 3300 KVA at 375 r. p. m., 6300 volts, 50 cycles at 80 % power factor, also two generators each of 1200 KVA 500 r. p. m. 6300 volts, 50 cycles at 80 % power factor, all generating power for the production of Calcium Carbide. The Arendals Fosse Kompagni's Installation at Böjlefos was originally supplied with 3 generators of 4670 KVA, 375 r. p. m., 25 cycles, 5000 volts at 80 % power factor, and one generator for 4375 KVA, 375 r. p. m., 50 cycles, 5000 volts at 80 % power factor, but the capacity was later increased by 3 additional 25 cycles generators so that in 1914 the completed power station had a capacity of 33000 KVA, which power, with the exception of the 50 cycles current generated for lighting and industrial purposes, is all utilised for large electro-chemical works.

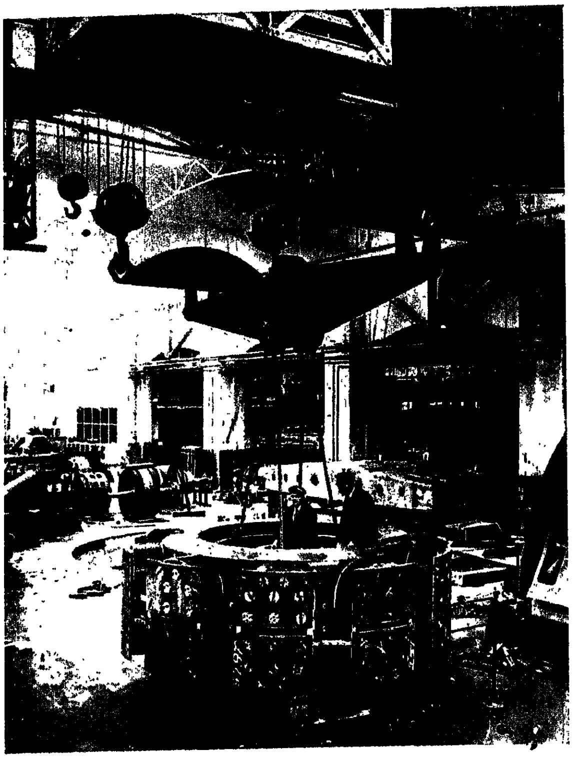


Fig. 39. Lifting of rotor.

In 1913, 3 three-phase generators each of 3750 KVA, 2300 volts, 163 r. p. m., 60 cycles at 80 % power factor were installed in the E. B. Eddy Co's power station in Canada; also the generators for Calgary, Nokia and Sagami, together with a great numer of others distributed all over the world and too numerous to mention individually. At the time of writing the generators for Glomfjord with a continuous rating of 22000 KVA are almost completed, and, big as they are, larger machines still have been designed. As early as 1915 Asea estimated and submitted tenders for three-phase generators of 35000 KVA to be driven by water turbines but the world disturbing political situation, at that time, frustrated this project. The tables on page 23 show that during the past advances in the size of generators Asea has held the record more than once.

It might be objected that it is not of such great importance if one Company or another should receive an order occasionally for a machine larger than any previously built, but such orders indicate that not only has the purchaser of the past confidence in the work previously executed by the Company, but also that he feels the manufacturer is able to produce a larger

Fig. 40. Flumes at Tysse.

The largest Hydro Electric Alternating Current Generators built by Asea.

Deliv. in	Maker	Customer	Power Plant	Number	Phases	Output KVA	Volts	r. p. m.	Cycles
1895	ASEA, Västerås	Dr. De Laval	Trollhättan	1	1	850	300	250	12.5
1903	» »	Örebro El. Co.	Brattfors	1	3	1830	20000	214	50
1905	» »	Tinfos Paper Mills	Tinfos	1	3	2830	5150	250	50
1907	» »	Norw. Hydro El. Kvælstof Co.	Svælgfos	4	3	10500	11000	250	50
1909	» »	The Swed. Gov.	Trollhättan	4	3	11000	11000	187.5	25
1915	» »	Norw. Hydro El. Kvælstof Co.	Rjukan II	6	3	18900	9500	250	50
1918	» »	The Norw. Gov.	Glomfjord	2	3	20000	15000	300	25
1921	» »	» » »	»	1	3	24000	15000	300	25

The Largest Hydro Electric Alternating Current Generators in the World.

Deliv. in	Maker	Customer	Power Plant	Number	Phases	Output KVA	Volts	r. p. m.	Cycles
1891	Oerlikon, Zürich AEG, Berlin	Oerlikon & AEG	Lauffen	1	3	210	86	150	40
1896	Westinghouse El. & Man. Co.	Niagara Falls Power Co.	Niagara	3	2	3750	2250	250	25
1905	D:o	Ontario Power Co.	D:o	6	3	7500	12000	187.5	25
1907	ASEA, Västerås	Norw. Hydr. El. Kvælstof Co.	Svælgfos	4	3	10500	11000	250	50
1909	Gen. El. Co. Schenectady	Great Western Power Co.	Big Bend, Feather riv.	4	3	12500	11000	400	60
1911.	D:o	Washington Water Power Co.	Spokane riv., Long Lake Dev. ment	2	3	13900	4000	200	60
1912	Brown Boveri Co.	Norw. Hydro El. Kvælstof Co.	Rjukan I	1	3	17000	11000	250	50
1913	Gen. El. Co. Schenectady	Pacific Light & Power Co.	Big Creek	2	3	17500	6600	375	50
1915	ASEA, Västerås	Norw. Hydro El. Kvælstof Co.	Rjukan II	6	3	18900	9500	250	50
1919	Allis Chalmers Mfg. Co.	Niagara falls Power Co.	Niagara	1	3	32500	12000	150	25

machine and at the same time one of equally high quality with the smaller sizes. In this respect Asea has maintained its customers' goodwill, amply demonstrated by the numerous repeat orders for extensions to existing installations. As an example of this it might be mentioned that more than fifty machines with an average output of 12300 KVA per machine have been delivered or are under construction in Asea's shops. If the Untra ge-

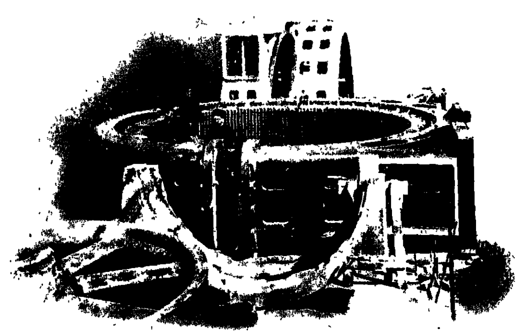


Fig. 42. Stator for large three-phase generator during construction.

nerators of 9000 KVA and the Porjus single phase generator of 6250 KVA (equal to 10000 KVA three-phase) are disregarded in this calculation, it brings the average up to over 13000 KVA per generator.

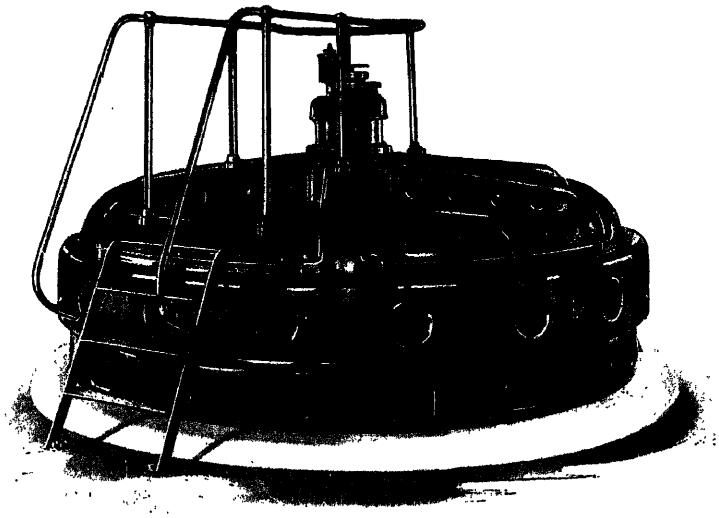


Fig. 13. Modern vertical three-phase generator.

SWEDISH INSTALLATIONS

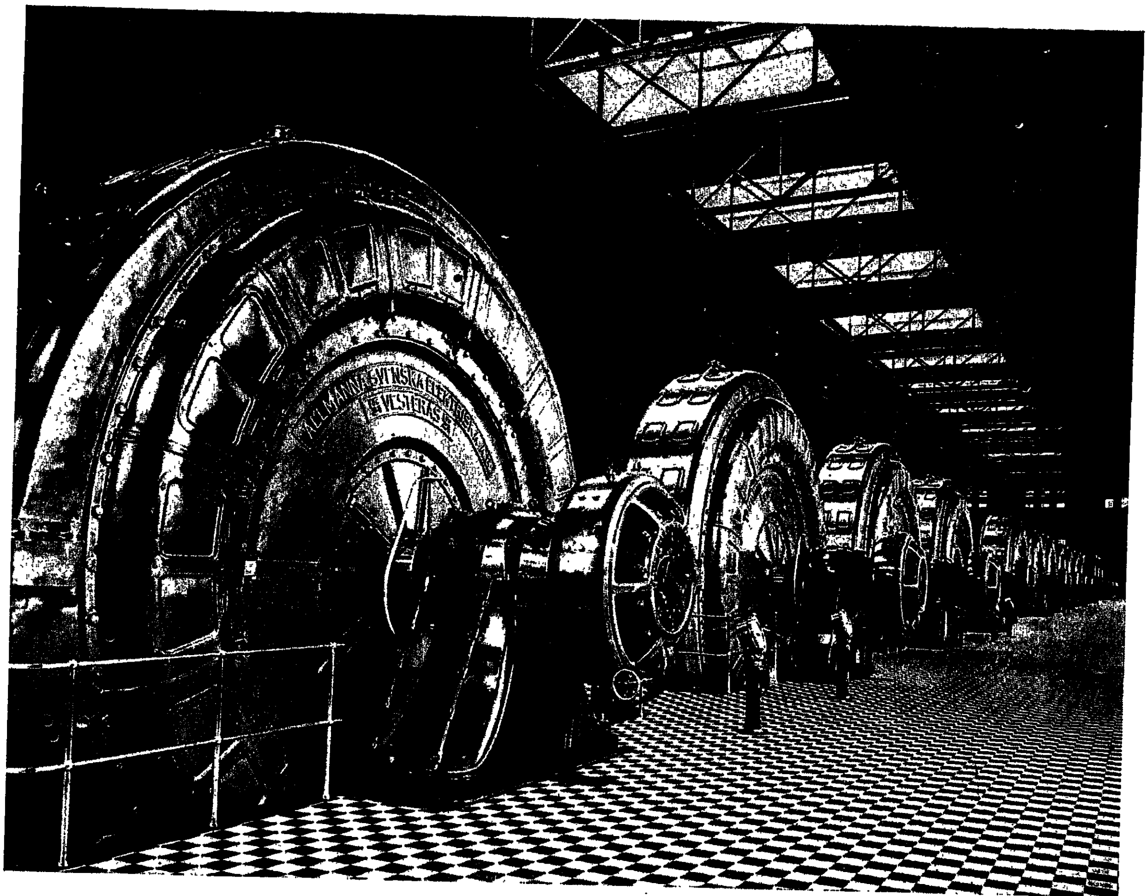


Fig. 44. Interior view of the machinery hall of Trollhättan Power Plant.

THE SWEDISH STATE POWER STATION AT TROLLHÄTTAN

FOR this power station, the first and largest of the Swedish State Water Power Stations, Asea received an order for four three-phase generators in 1908, and during the following years repeat orders for nine more sets were received, the last two for delivery in 1918. Though the pamphlet entitled "Trollhättan Power Plant" issued by Asea in 1912 after the completion of this power station, describing in detail both the power station and the generators, is doubtless well known to the reader, it might be of interest to repeat the general dimensions of these generators, as they were the first totally enclosed machines of this size built by Asea, also when installed they were amongst the largest three-phase generators direct

Fig. 45. Exterior view of Trollhättan Power Plant.

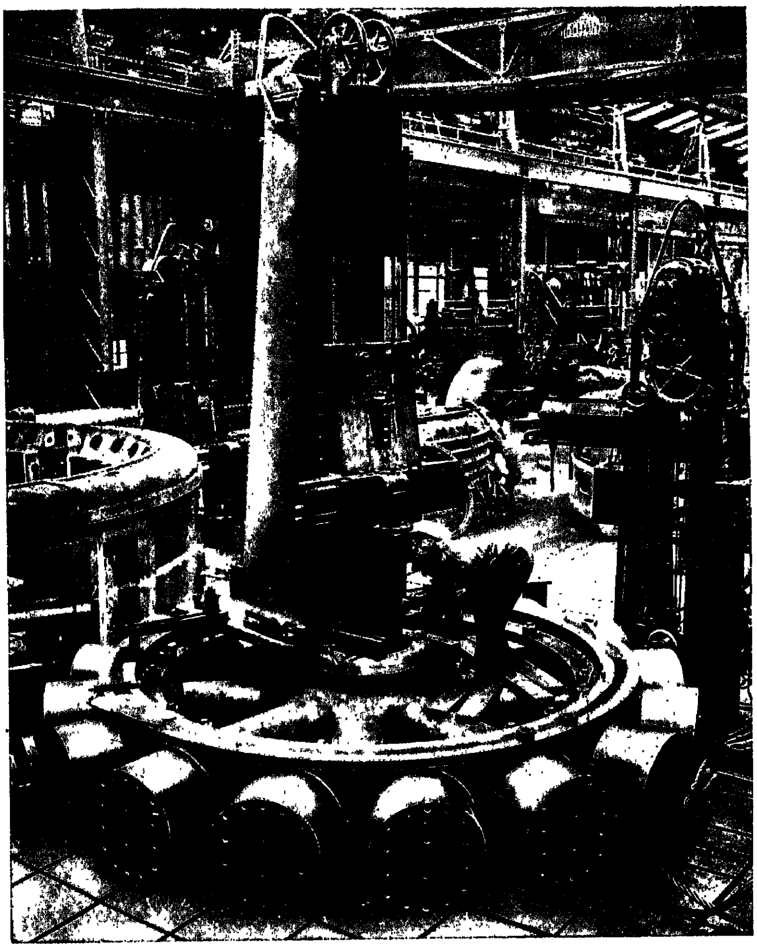


Fig. 46. Rotor for Trollhättan generator during construction.

coupled to water turbines. They have, moreover, in many ways formed the basis on which other Asea totally enclosed generators have been designed.

Each of these thirteen generators is designed for a continuous output of 11000 KVA at 10000 to 11000 V, 187.5 r. p. m., 25 cycles at a power factor of 80 %; they are arranged with the armature winding in the stator frame and rotating field on a horizontal shaft with a solid flange for coupling to the turbines.

The stator frame is of cast iron of massive "box section" construction to ensure the requisite rigidity, and also to allow the hot air from the laminations and windings to pass readily to the outlet situated at the bottom of the machine, from whence it is carried away in ducts. Other parts of the stator frame, with the exception of the bottom portion, have openings with cast iron inspection covers which can be removed to allow the hot air to escape into the power house if desired. The stator is split horizontally, the greatest overall dimension is 7.38 metres and the greatest height 6.72 metres.

The laminations are dovetailed into the stator frame, secured in carefully machined slots, and held together laterally by heavy forged steel rings. To secure ample ventilation, air ducts are provided at suitable intervals. The outside diameter of armature stampings is 5.5 metres, the inside diameter 4.7 metres and the length axially 0.9 metres. The material used is the highest quality Swedish laminated sheet 0.5 mm thick, the stampings being insulated from one another by means of paper pasted and rolled on before the sheets are stamped. The

Fig. 47. One of the water falls at Trollhättan.

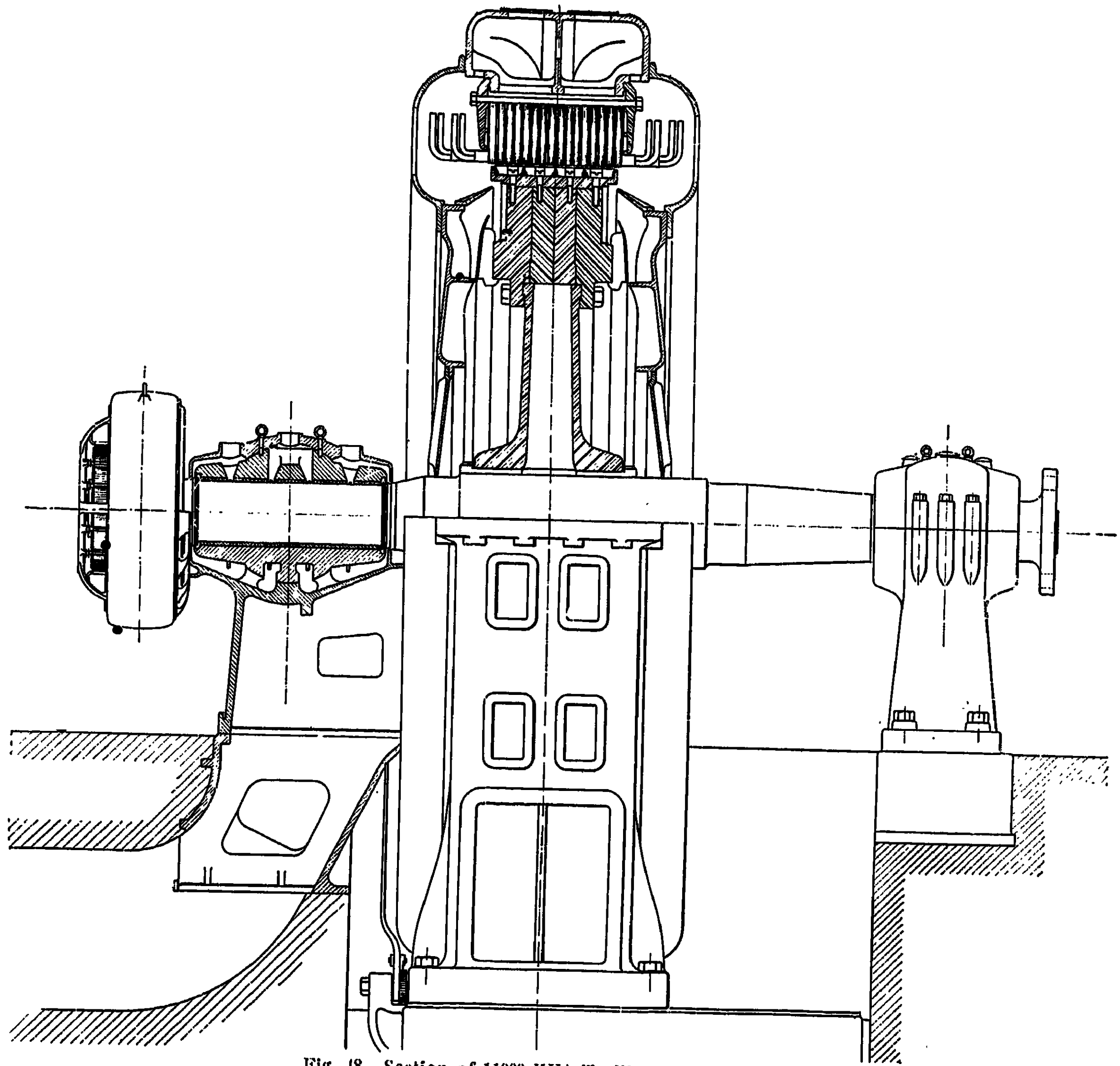


Fig. 48. Section of 11000 KVA Trollhättan generator.

stator laminations are provided with 192 open slots for the reception of the winding, and the coils are arranged in two planes; there are four slots per pole per phase and four conductors per slot, each conductor consisting of several copper bars insulated with cotton and impregnated. The bars forming each conductor are then insulated with a patent micanite insulation and the whole of the conductors in each slot are insulated from the frame by seamless micanite tubes. In this way the insulation between copper and iron is built up of three distinct parts all forming a homogenous mass by baking after being specially compounded; the total insulation aggregates about 5 mm.

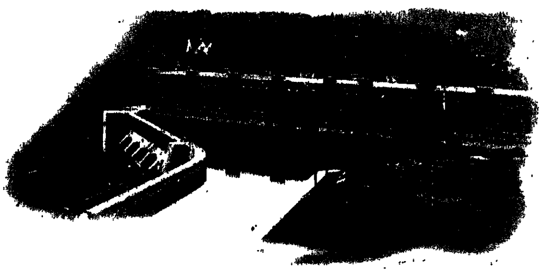


Fig. 49. View of the forebay and intake building of Trollhättan Power Plant.

Outside the laminations the conductors are divided into two groups, each insulated in the customary manner, coated with insulating material and a special smooth surface finishing varnish to minimise accumulation of dust. To prevent distortion on short circuits or heavy surges on the line, each coil is secured to substantial brackets which obviate any risk of the coils pulling out of shape. During the very thorough tests to which these machines were subjected, a short circuit was thrown onto one

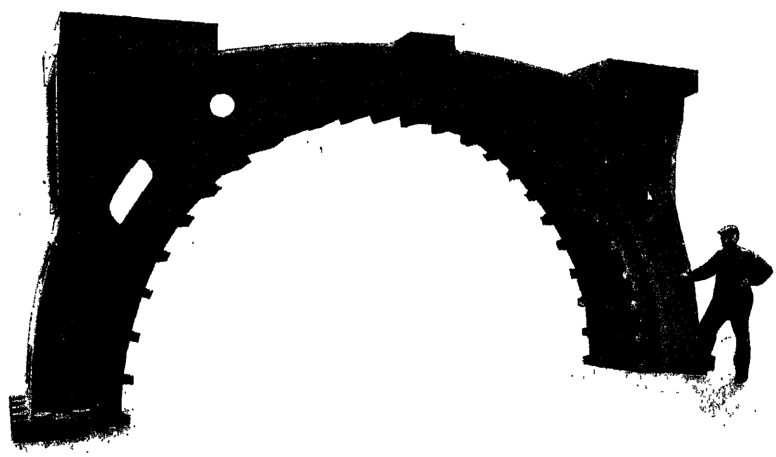


Fig. 50. Lower half of a stator for Trollhättan generator.

of the machines and after this had been repeated several times the machine was shut down for examination, but no distortion of the coils could be traced. Owing to the very liberal insulation no trouble was anticipated or encountered in fulfilling the insulation guarantees: the winding was tested to earth between phases with 20000 volts, 50 cycles for a period of 15 minutes. The housing over windings and the side plates round the shaft are all of cast iron: this material was selected for two reasons, firstly because a more pleasing contour and finish could be obtained, and secondly because a better fit is possible, thus eliminating all danger of air leakage which might cause unpleasant whistling noises. The illustration indicates how the first point is effected and a visit to the power house will demonstrate the second: it is no exaggeration to say that the machines run quite noiselessly. To get over the difficulty of taking all the end shields off for inspection purposes, small doors of light weight are fitted to the main shields: these allow not only quick inspection, but also cleaning of the coils.

In the event of more thorough inspection or repairs being necessary to the stator or rotor, the former can be moved axially on slides after the end shields have been removed, so that the

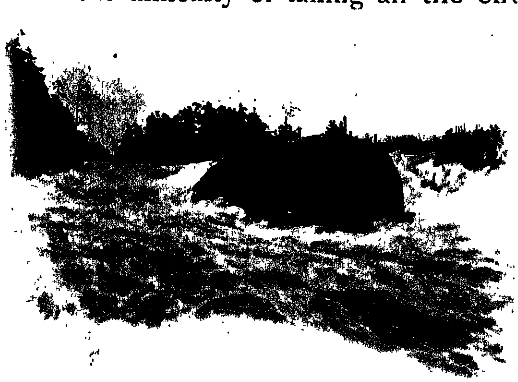


Fig. 51. Gullö Falls, Trollhättan.

coils in both stator and rotor can be taken out without lifting the rotor from its bearings or moving it in any way.

The rotor, with the exception of the poleshoes and small details, is made of Siemens-Martin Steel. The polepieces and outer ring of the magnet wheel are Asea standard construction, *i. e.* without joint, but to facilitate transport and also to make sure that the material is free from blowholes and flaws the polepiece rings are

Fig. 52. Special train loaded with rotor parts for Trollhättan generator.

made up in pancake sections; these rings or sections are held together by bolts and shrunk on the rotor centre which consists of a spider with eight hollow arms, the arms being hollow to make the construction as light and strong as possible; they are of cast steel in one piece with the hub.

The sixteen poles are circular machined all over; the bottom part of the pole shoes are made of Siemens-Martin Steel into which the laminated face plates are dovetailed, and the complete shoe is bolted to the polepiece. The poleshoes are laminated to prevent eddy currents on account of the open slots. One of the generators has the poleshoes so arranged that damping windings can be inserted at some future date in order that it can be used as a single-phase machine for electric railway service, for which it is eventually intended.

The field winding consists of 140 turns of copper strip wound on edge, insulated in the usual manner and tested to earth with 4000 volts alternating current for 15 minutes. Fan blades are fastened to the rotor to circulate the necessary air for cooling the machine.

The shaft which is made of the best Swedish steel is bored with hollow cutters, the core being taken out and tested, to make sure that the steel is perfect throughout.

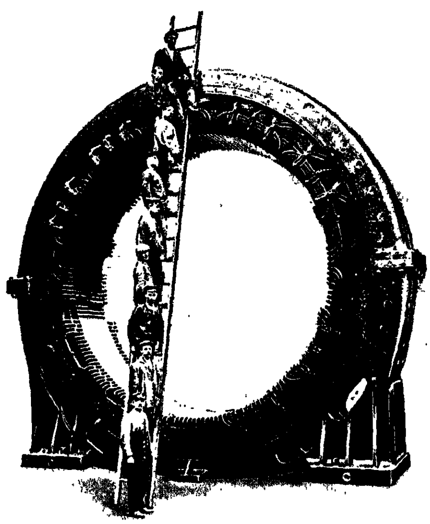


Fig. 53. Stator for Trollhättan generator.

The hole in the shaft is utilized to bring out connections from the field winding to the collector rings, which are placed at the extreme end outside the exciter armature. Owing to the special arrangement for moving the stator axially, the distance between the bearings is necessarily great, hence a stiff shaft is required; it's dimensions are 6.5 metres long, greatest diameter 0.6 metres and weight 9 tons.

The flywheel capacity, G. D^2, of the rotating masses is about 3600000 kgm^2.

The bearings are of common ring oiling type, but with water cooled bushings.

The generators are excited from a central D. C. supply of 220 volts. From this the current is taken through an auxiliary exciter on the rotor shaft of the generator. This exciter is designed for a potential of +110—220 volts so as to regulate the exciting voltage of the three-phase generator between 330 and 0 volts. By this means the use of series resistances is avoided and the voltage of the generator is regulated only by regulating the field of the auxiliary exciter.

The weight of each generator is 200 tons, the stator weighing 102 tons, rotor 67 tons, bearings and bedplate 22 tons.

Fig. 51. Granite sculpture of "The Water Sprite" on the dam at Trollhättan.

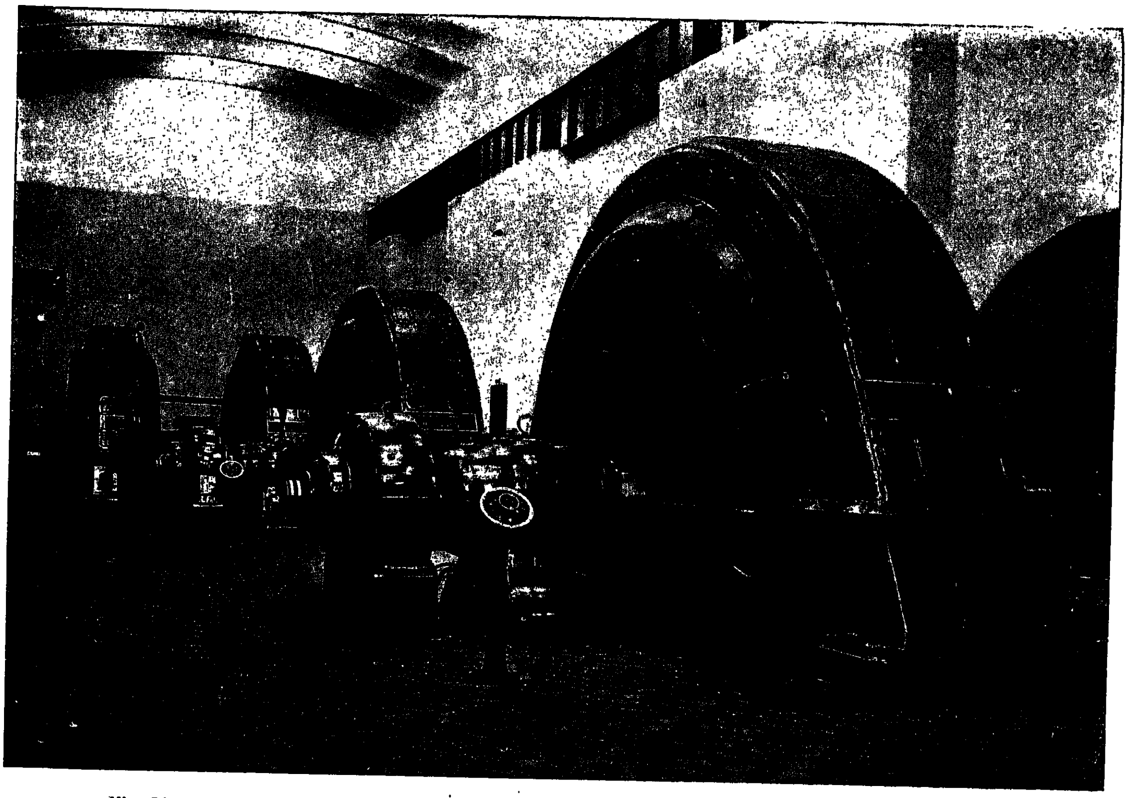


Fig. 55. The machinery hall of the Swedish State Power Station at Porjus after first extension.

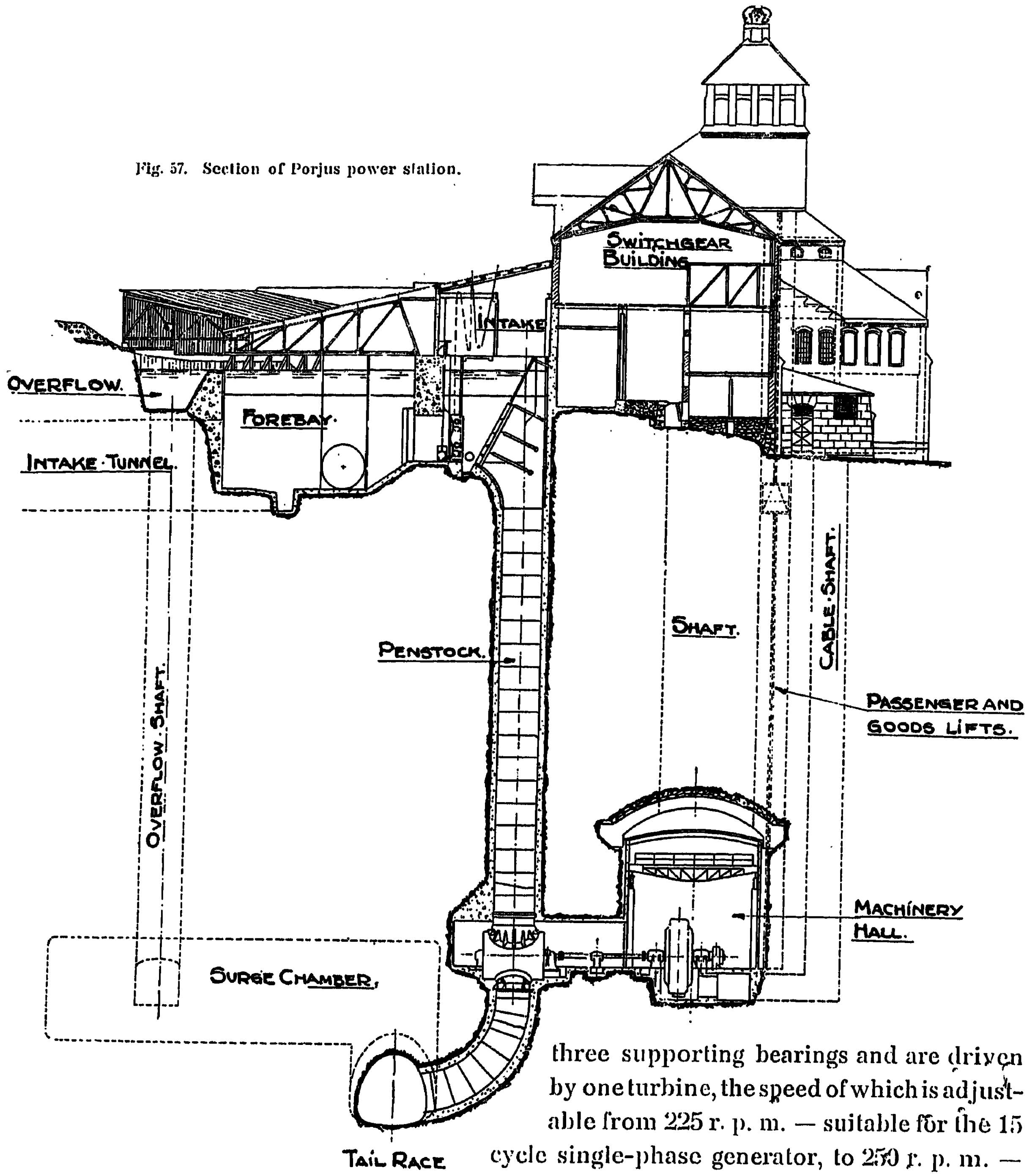
THE SWEDISH STATE POWER-STATION AT PORJUS

I. THREE-PHASE GENERATORS

DURING 1914 Asea supplied the Swedish State Power Station at Porjus on the Lule river, with two three-phase generators rated at 11000 KVA, 250 cycles, 10000—11000 volts at 80 % power factor. Three years later Asea received a repeat order for two more generators, duplicates of those previously supplied. These generators, of which one is a spare for the time being, supply power for industrial use and ore fields at Gällivare, Kiruna and other adjacent places. The power house is located about 50 metres below the ground level and is hewn out of the solid granite; each generator is driven by an independent water turbine of 12500 HP. The spare three-phase generator and a spare single-phase generator, are erected in line with

Fig. 56. The "Big Lake" Falls on the Lule River.

Fig. 57. Section of Porjus power station.



three supporting bearings and are driven by one turbine, the speed of which is adjustable from 225 r. p. m. — suitable for the 15 cycle single-phase generator, to 250 r. p. m. — suitable for the 25 cycle three-phase generator. The generators are totally enclosed and self-ventilated by fan blades fitted to the rotor. The stator carries the armature winding and the rotating field is fixed to a horizontal shaft with flange for direct coupling to turbine.

Fig. 58. Transformer and Switch House at Porjus.

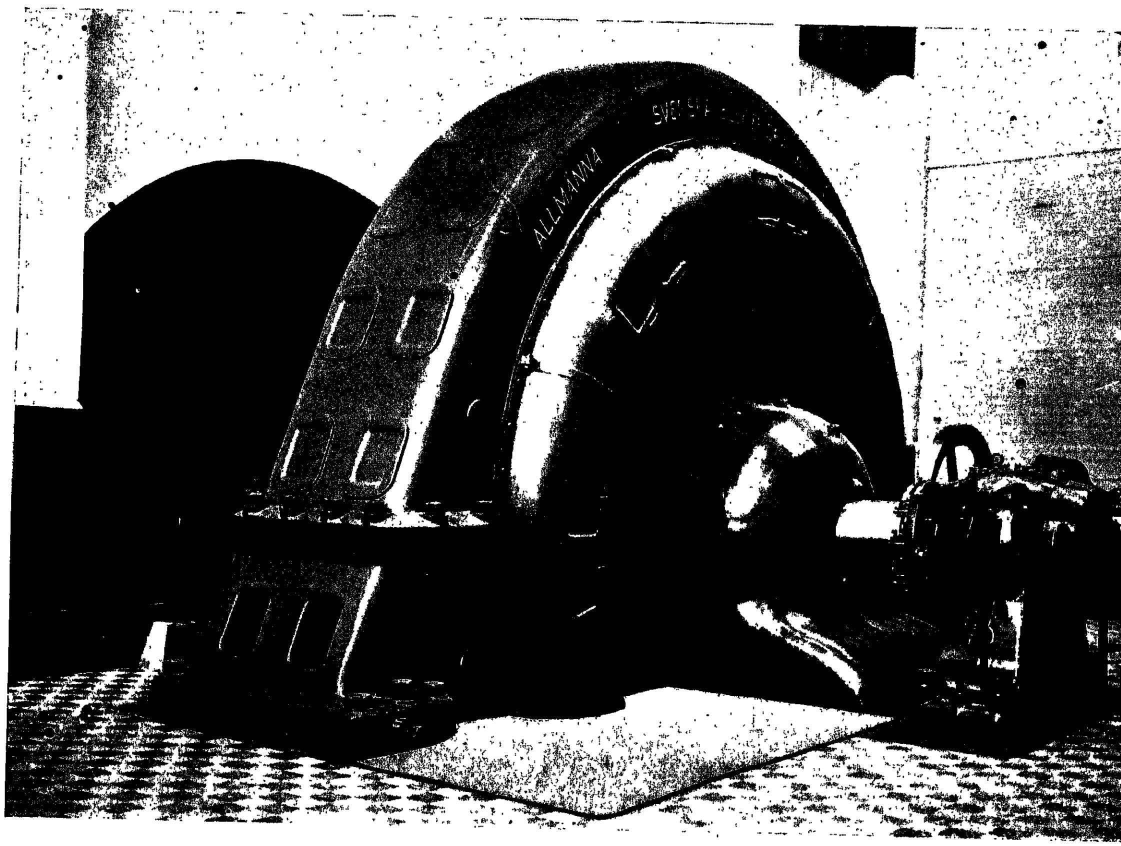


Fig. 59. 11000 KVA three-phase generator at Porjus power station.

The stator frame, cover plates and air ducts for in and outgoing cooling air are of cast iron. The largest overall dimension of the stator, taken horizontally at the base, is 7.8 metres and the vertical diameter 6.3 metres. To facilitate repairs the stator is placed on slides so that it may be moved axially. The armature is built up of standard laminated sheets, dovetailed into stator frame and held together with steel rings pressed and bolted in place; the outside diameter is 5 metres, inside 4,15 metres and thickness axially 0,9 meter.

The armature winding is arranged in two planes, 6 slots per pole per phase with three conductors per slot; the conductors are subdivided with all sub-divisions insulated from each other and from the frame with micanite: as a result the windings can easily withstand 20000 volts alternating current between phases as well as to earth. Owing to the special arrangement for bracing the coil ends and the adequate way in which they are secured, the machine can stand heavy short circuits with full excitation. The machine is Y-connected with a separate connection taken from the neutral point.

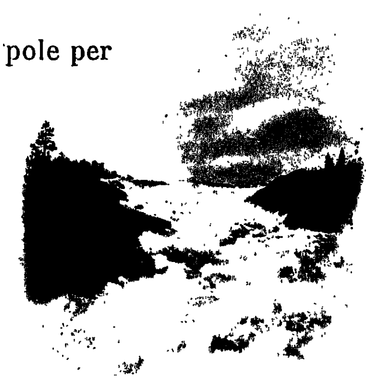


Fig. 60. The "Hare Leap", Lule River.

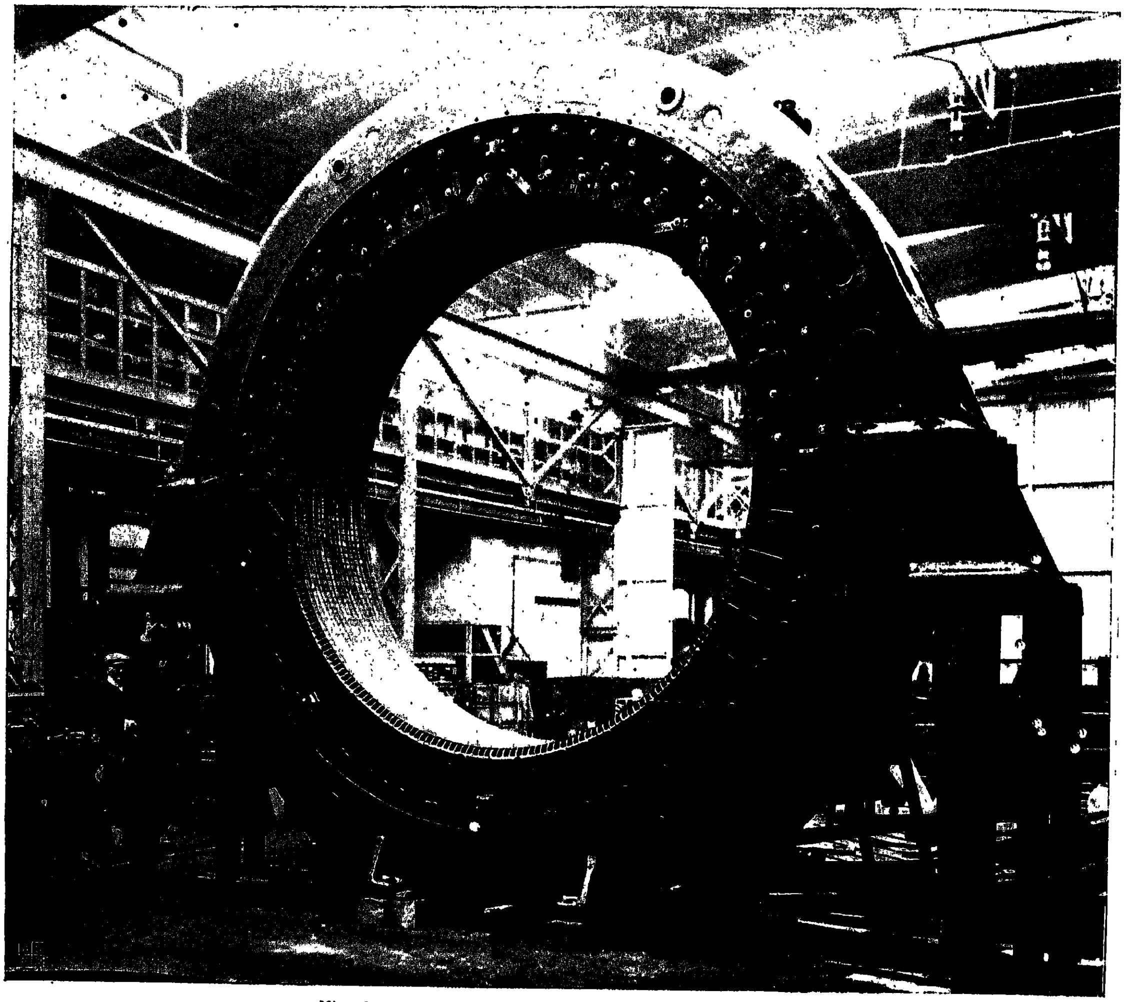


Fig. 61. Stator of single-phase Porjus generator.

The 12-pole rotor is standard construction made of Siemens-Martin Steel with polepieces and outer ring in one, divided in ring sections, these being held together by bolts and shrunk on the rotor. The poleshoes are laminated and bolted to the polepieces. The field winding consists of 111 turns of copper strip wound on edge insulated to stand 4000 volts alternating current to earth for 15 minutes. Special attention has been given to the question of moisture brought in with the cooling air, which in older installations has shown a tendency to condense on the rotor arms from whence it was thrown on to the field windings. The flywheel effect of the rotor is about 4200000 kgms — the shaft and bearings are of standard construction. At the present

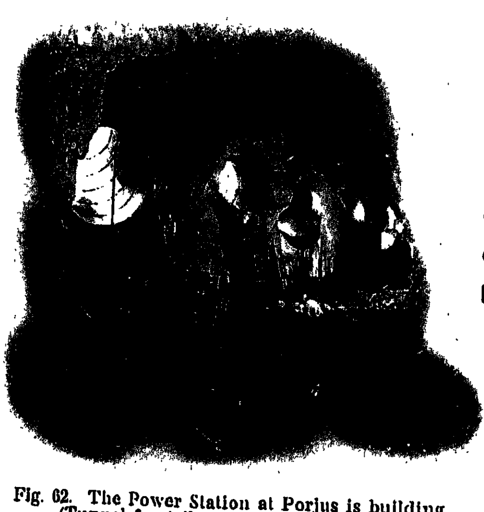


Fig. 62. The Power Station at Porjus is building. (Tunnel for tail-race with draft tubes).

Fig. 63. Express train on the Riksgräns Electric Railway Line operated with power from Porjus.

time the generators are excited from a central D. C. supply, but as soon as all the generators are installed, each machine will be equipped with a separate direct coupled exciter.

The weight of each machine is about 165 tons. The air cooling system is arranged somewhat differently to that provided with similar plants of about the same size. As already mentioned, the rotors are equipped with fan blades which serve to distribute the air and force it through the different channels. Air is blown into the machines from air ducts which receive their supply from two pressure fans located in the switch house: each fan has a capacity of 125 cub. metres per second at a pressure of 50 mm water gauge. These fans suck the air from intakes outside the building, which in summer time are fitted with mosquito nets, and force the air through the different air ducts to the machines, thence to such rooms that require heating, and finally to the switchroom: in winter very little air is taken from outside the power station as the air in the building is circulated through the machines.

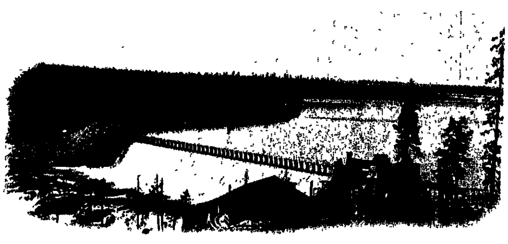


Fig. 64. The dam, Porjus.

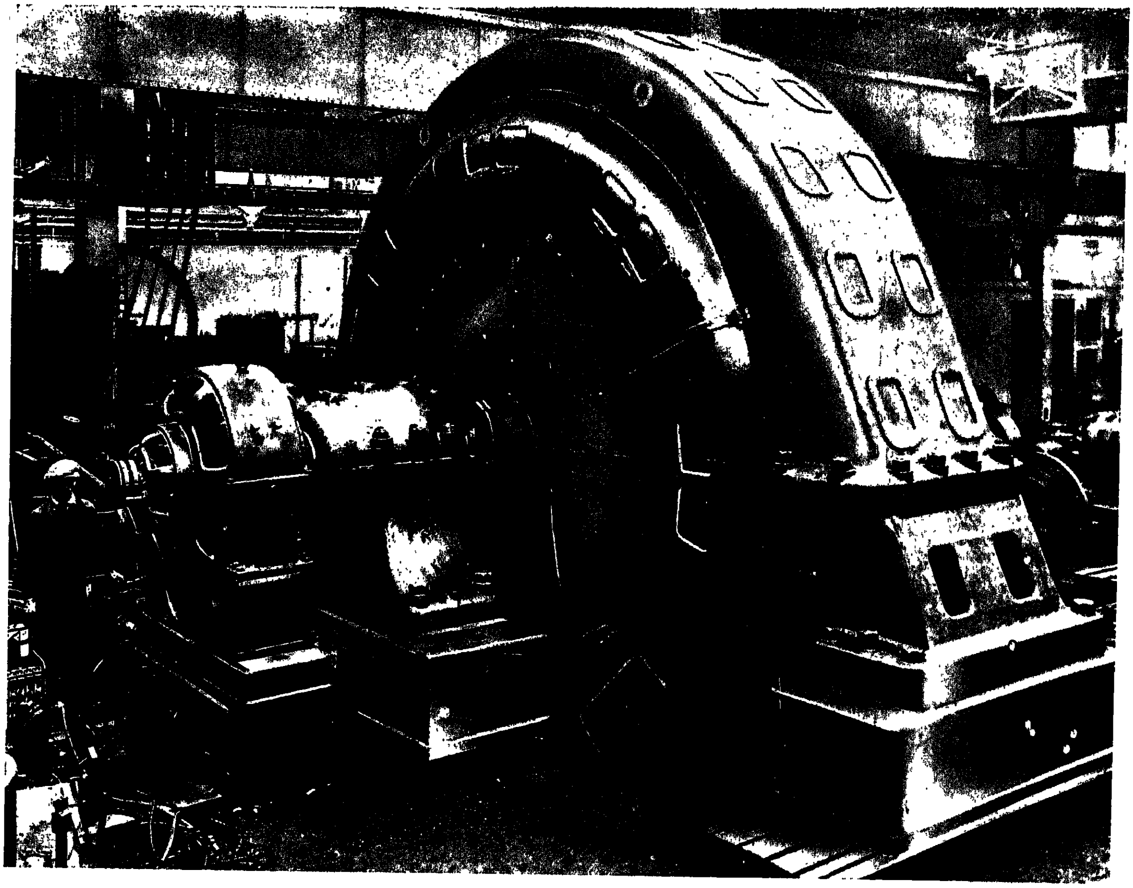


Fig. 65. Single-phase generator on the test bed for large machines.

II. SINGLE-PHASE GENERATORS

At the same time as the three-phase generators mentioned above were delivered, Asea also furnished Porjus with three single-phase generators built for a continuous output of 6250 KVA at 4000 volts, 225 r. p. m. — 15 cycles — at 80 % power factor.

These generators supply power for the Riksgränsbanan Electric Railway and are erected in the same underground power station as the three-phase generators described above. Two of the generators are each coupled to a 12500 HP turbine but the third, together with one of the three-phase generators is coupled to one turbine as previously mentioned; this unit is the spare for both the single- and three-phase plant.

Fig. 66. The "Big Lake", Porjus.

Owing to the customary heavy peaks encountered in electric traction service, the generators are designed to deal with an overload of 10000 KVA

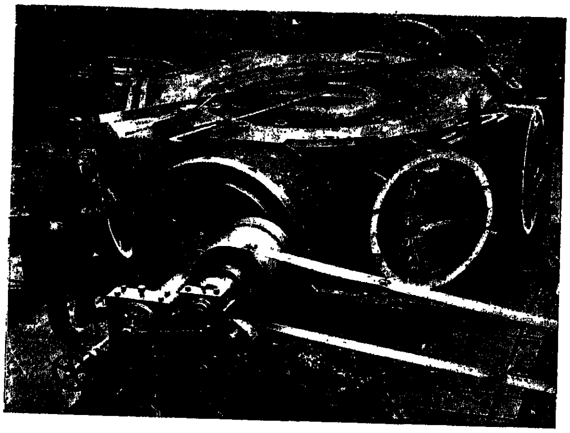


Fig. 67. Rotor during construction.

at 80 % power factor. The machines are compounded on the Davidson system so that at an overload of 10000 KVA the voltage rises 20 % above the normal light load potential.

As the distance between the power station and the railway is considerable, the highest permissible line voltage was the most advantageous; this necessitated stepping up the generator voltage, which was accordingly selected to secure the greatest reliability, that is to say, a winding which would be electrically and mechanically strong and at the same time easy to repair. It was found that 4000 volts would be the most suitable as at this voltage a bar winding could be used having only one bar per slot. To minimise losses each conductor is divided into two with micanite insulation between, and the whole is then insulated from the frame with moulded micanite. Outside the laminations the bars are connected with substantial end connectors supported on heavily insulated non-magnetic brackets, thus giving a strong and rigid construction to enable the machines to withstand heavy short circuits with full excitation.

The stator frame and coverplates are of cast-iron and the frame constructed to form a chamber or duct for the hot air emanating from the machine. The laminations, which, due to the small number of poles (only 8), are unusually substantial, are, in accordance with standard practice, dovetailed into the stator frame and clamped with steel rings put on under heavy pressure. These rings are designed with fingers extending towards the air gap, each finger pressing on the laminations between two slots, thereby giving an even pressure and adequate support from the air gap to the stator frame. The steel rings are held in place by heavy bolts well insulated and placed at the centre and near the outer edge of the laminations. All laminations are, as usual, divided up into sections separated by suitable spacing pieces to permit egress of cooling air. There are 240 slots of which 160 contain the winding. The inside diameter of the stator is 4 metres, outside diameter 5 metres and the thickness axially 1.05 metre.

The rotor is Asea's standard construction for large machines, built up of a number of steel rings having the polepieces and ring in one piece and shrunk on a steel hub; six such rings are used on each machine, the weight of each ring being about 10 tons.

The polepieces are laminated, with a regular bar

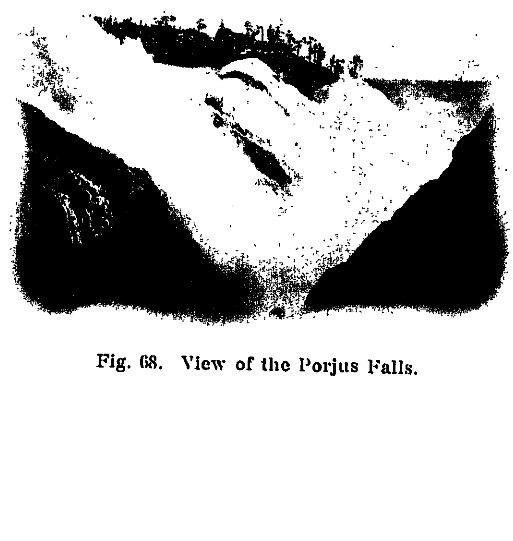


Fig. 68. View of the Porjus Falls.

winding embedded in half open slots, and are dovetailed to the solid part of the pole-shoes and these again are held to the polepieces by bayonet locks, thus assuring a rigid connection to the polepieces for these exceptionally heavy poleshoes. The damping winding bars are connected to short circuiting rings outside the poleshoes and are carried on extensions to the shoes to allow free circulation of cooling air to all parts; to obviate vibration these short circuiting rings are braced to the pole ring.

The field winding consists of 120 turns of copper strip on edge per pole; the inside diameter of each field coil is 1.05 meter. To prevent undue heating of the field coils they are designed with cooling fins consisting of wide copper bands, about 20 mm apart, placed between the turns of the coils; by this means the cooling surface of the coils is greatly increased and the temperature considerably lower than that obtained in coils without this device.

The shaft is counter-bored its full length and has a solid flange for coupling to turbine and an extension for the exciter armature.

The bearings are water cooled with standard ring oilers, one of the bearings is insulated from ground to prevent the circulation of heavy parasitic currents. The flywheel effect of the rotating masses is 4000000 kgms. The ventilation of the machine is effectively accomplished by means of fan blades fastened to the rotor, which draw air from the common air duct supplying all the generators, as already described in the articles on three-phase generators. To insure an even temperature throughout the machine the rotor is designed with two radial air channels which force air through openings in the poleshoes, whereby a strong current of air is projected against the stator laminations.

The weight of the generator is about 200 tons of which approximately 85 tons is in the rotor. As already mentioned the machines were designed on very liberal lines as proved by the test figures, which demonstrated that the efficiency at full load was 2 % higher than the guarantees without taking into consideration losses from eddy currents in copper and other parts. The temperature rise in all parts of the machine is very low and considerably under the guarantee. Short circuits were deliberately made during the tests without the least detrimental effect, although the current reached approximately 15 times the normal full load value.

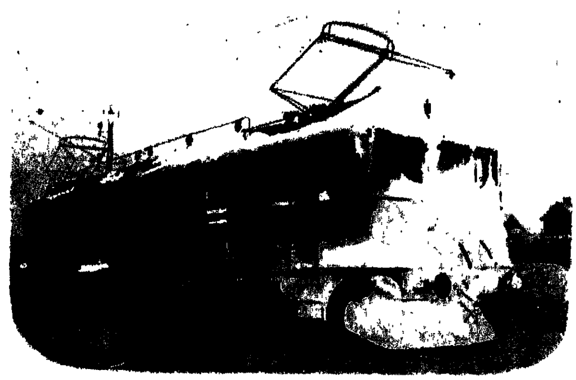


Fig. 60. Electric locomotive on the Porjus Riksgräns Railway Line. The day's work is over.

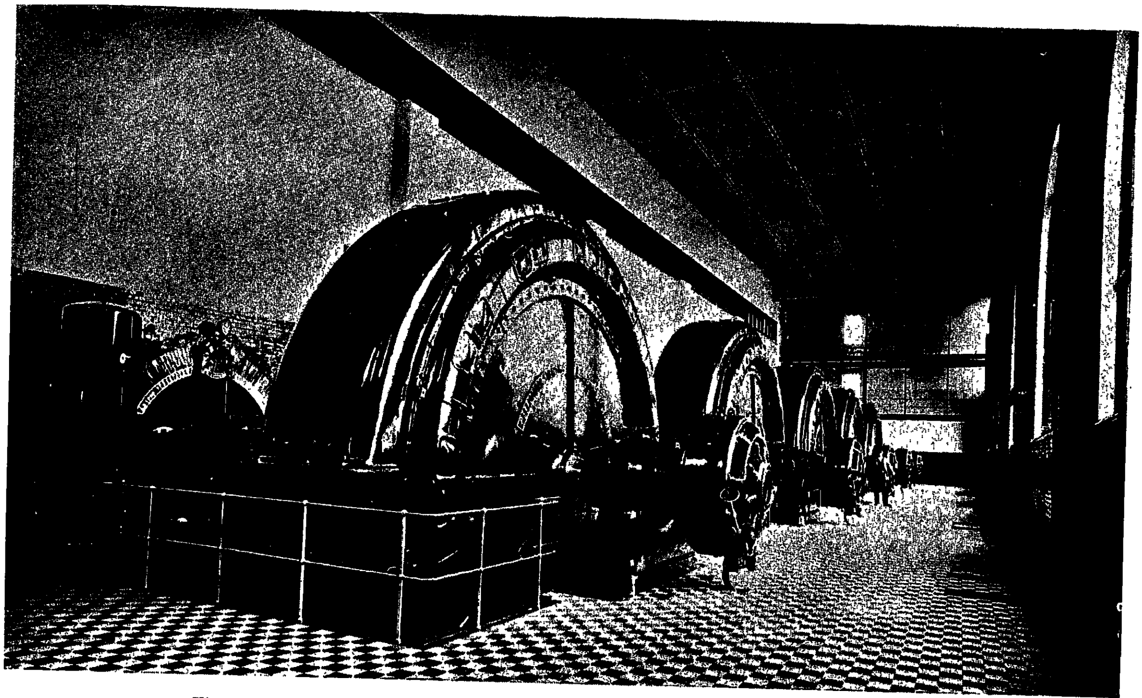


Fig. 70. The machinery hall of the Swedish State Power Station at Älvkarleby.

THE SWEDISH STATE POWER STATION AT ALVKARLEBY

THE Älvkarleby power scheme consists of a water power station at Alvkarleby with standby steam turbine station at Västerås, a very big power network embracing the Swedish provinces of Uppland, Södermanland, Västmanland, Dalarna and Gästrikland with transmission lines for 70000, 40000, 20000 and 10000 volts, transformer-stations, sub-stations, etc.

At the power station at Älvkarleby, located on the river Dalälven, about 8 kms from its outflow into the Baltic Sea, there is approximately 250 cubic metres of water available per sec with a head of about 17 metres. The power derived from this water is utilized by means of five four-wheel turbines with direct connected three-phase 10000 KVA generators, 10000—11000 volts, 150 r. p. m., 50 cycles at 80 % power factor.

After much discussion as to the frequency which should be adopted, three of the generators were eventually ordered in the Autumn of 1913 and delivered in the Spring of 1915. The other two were ordered in 1914 and delivered in the latter part of 1915.

Fig. 71. Älvkarleby power station during construction.

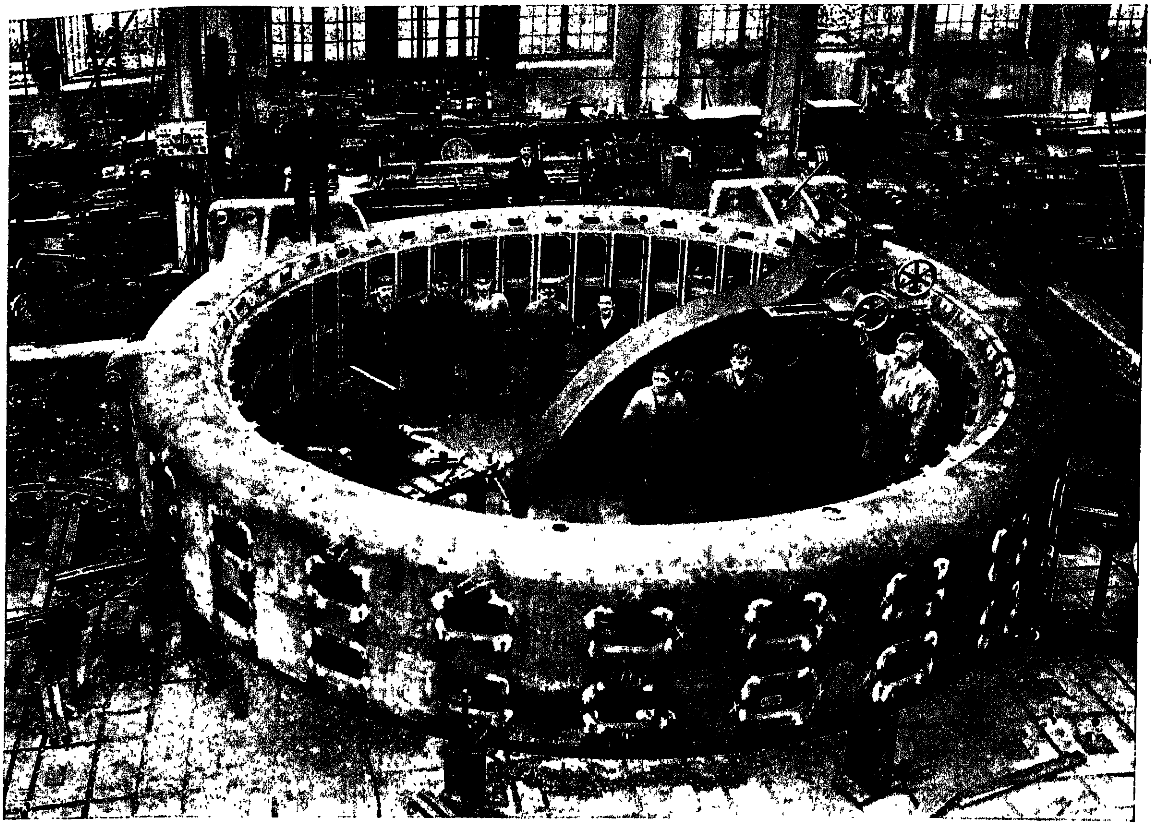


Fig. 72. Stator for Älvkarleby generator.

All the generators are totally enclosed, self exciting and self ventilating. In general these machines are similar to those supplied for Trollhättan, excepting for such changes as were necessary owing to different frequency and speed.

The outer diameter of the laminations is 6.0 metres and inside diameter 5.45 metres with an axial length of 1.15 metres. The largest overall dimension of the stator taken outside the feet at the centre line is 7.95 metres and the vertical diameter is 7.2 metres.

The winding is arranged in two planes, well braced, each coil being divided up into three open slots per pole per phase with two conductors per slot. Each conductor is subdivided and separately insulated, the whole being insulated from the frame by micanite. The rotor is of Siemens-Martin Steel, but owing to its great size and also because it is bad practice to split the rotor ring, the polepieces were made separately and secured to the ring by bolts. Even with this arrangement the outside dimension of the rotor ring was very close to

Fig. 73. The switch-house of Älvkarleby power station.

the stipulated railway clearances, and had it been larger it would not have been possible to transport by rail from Västerås to Älvkarleby; special railway trucks had to be used and the rotor ring so placed that its lower egde cleared the rails with only a few inches to spare.

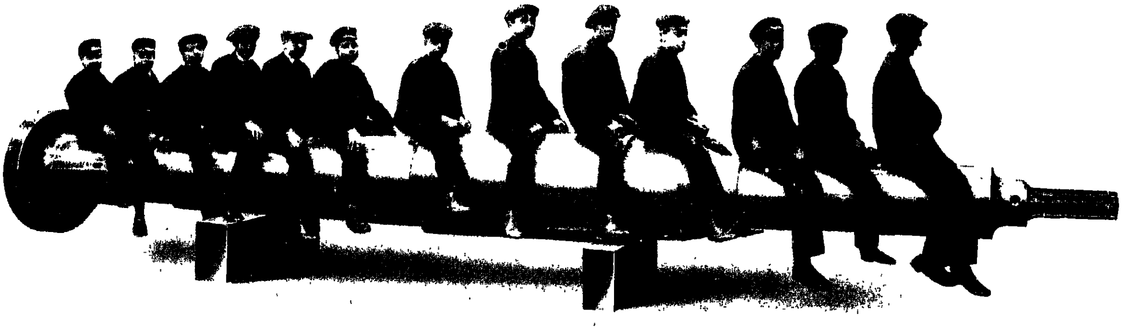


Fig. 74. Rotor shaft for one of the generators for Älvkarleby power station.

The ring and polepieces are divided by a gap right through the centre, from which a strong current of cooling air passes, impinging on the centre of the stator laminations. Apart from this, ventilation is also obtained by fan blades fixed to the rotor, which draw in cool air from the ventilating system, forcing it over the windings and laminations and out through the box section of the stator frame, thence through a duct to the warm air system.

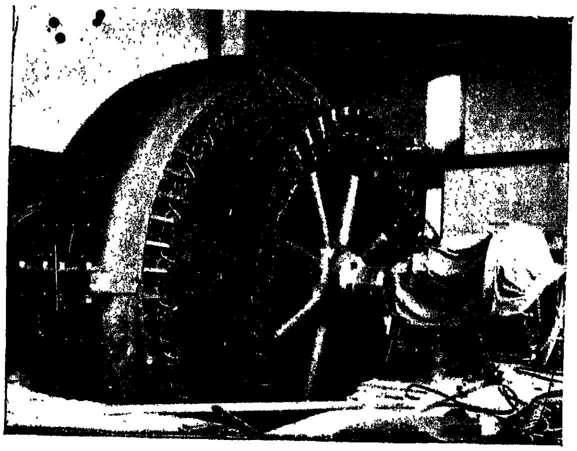


Fig. 75. Generator during erection in the power station.

The poleshoes are laminated and dovetailed to special extensions cast in one with the polepieces. This more or less unusual construction was used on account of the railway clearance and as the rotor ring and polepieces could not be made in one casting there was no object in making the poleshoes and polepieces in two separate parts; it proved just as easy to take off the field coil and polepiece together as the method of taking off the shoe and then the coil. Each field coil consists of 37 turns of copper strip on edge.

The hub as well as the ring and polepieces are of cast steel with six hollow arms, to which the rotor ring is attached. The shaft is made

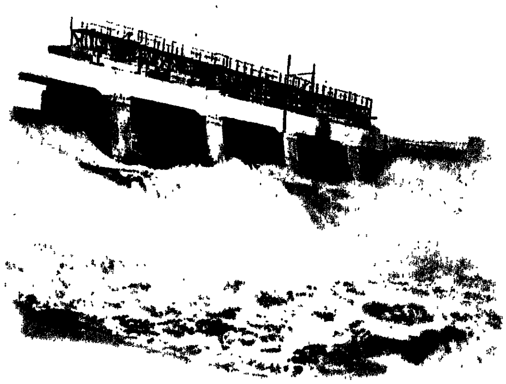


Fig. 76. The main dam.

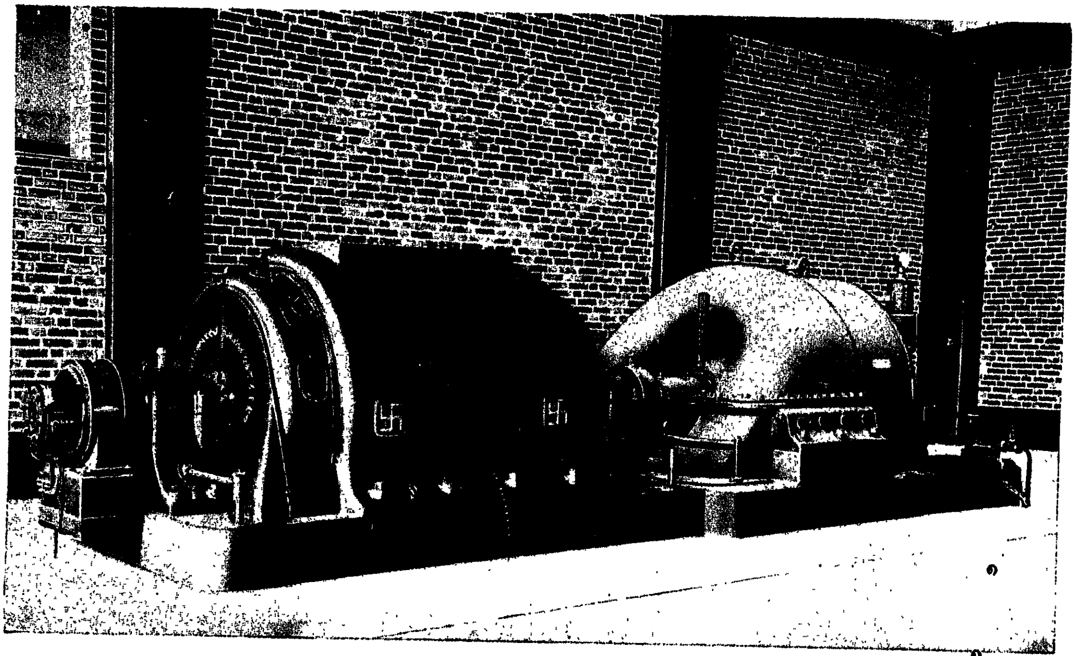


Fig. 77. Three-phase turbo-alternator, 8750 KVA, 7000 volts, 3000 r. p. m., 50 cycles in the steam emergency station at Västerås.

with a solid flange for direct coupling to the turbine, and is counterbored the full length. The bearings are standard, oil ring lubricating and water cooled; the flywheel effect of the rotating masses is about 3600000 kgms.

The weight of each generator is approximately 190 tons; of this 95 tons is in the stator and 70 tons in rotor, the remainder in bedplate, bearings, etc. The weight of the exciter is about 5 tons.

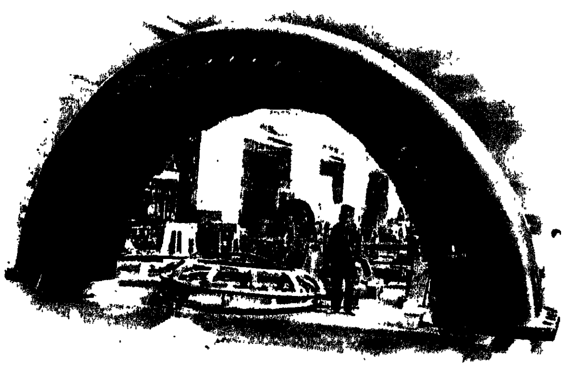


Fig. 78. The top half of stator of Älvkarleby generator.

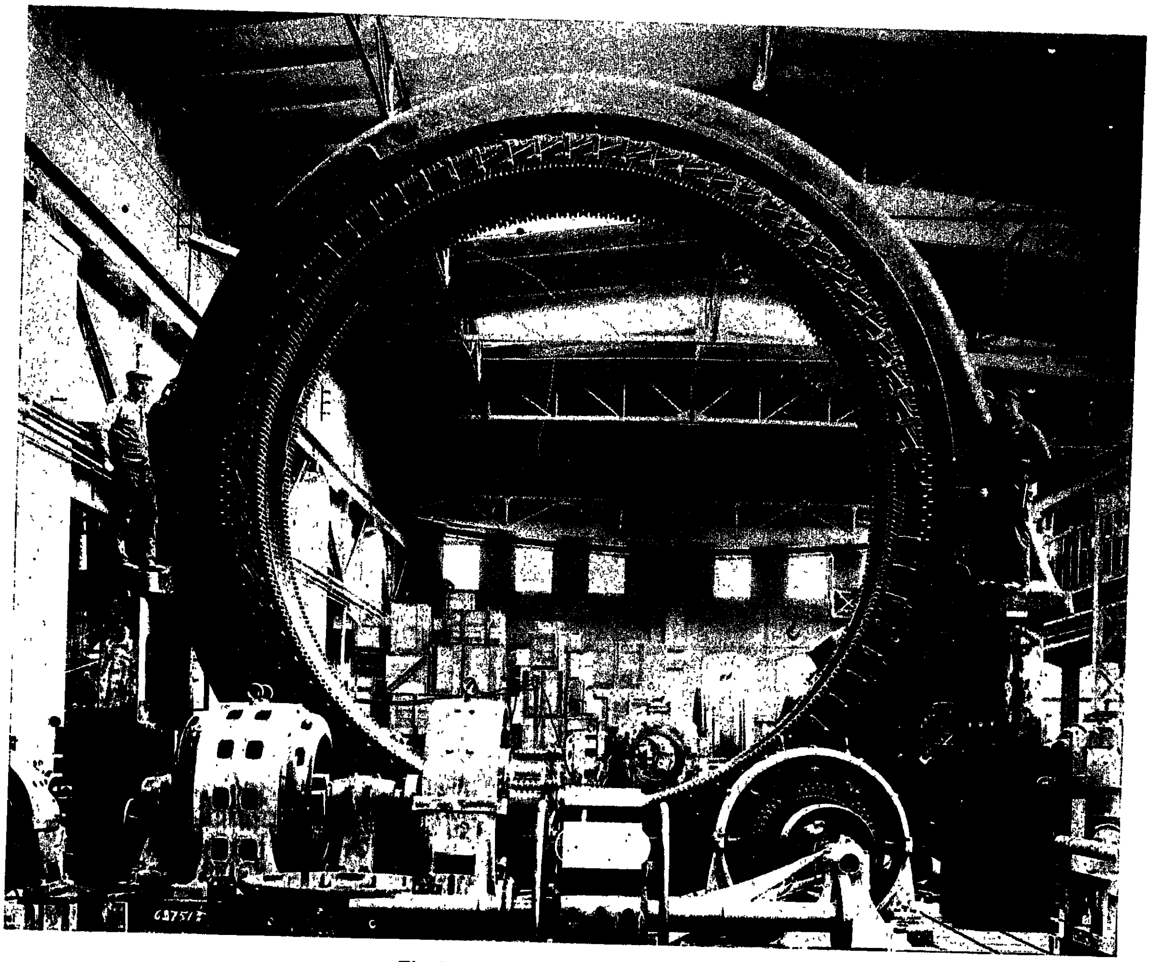


Fig. 79. Stator of Untra generator.

THE CITY OF STOCKHOLM'S POWER STATION AT UNTRA

FOR some time past the management of the City of Stockholm's Power Station had been considering the advisability of constructing a water power station, which, in conjunction with the steam power house at Värtan, could deal with the rapidly increasing demand for electrical energy.

Consequently in 1904, the City Authorities purchased the waterfalls at Untra on the river Dalälven, but legal difficulties arose and the building operations for the station could not be started until 1912.

These falls, located about 30 kms from the river's outflow into the Baltic Sea, had a total

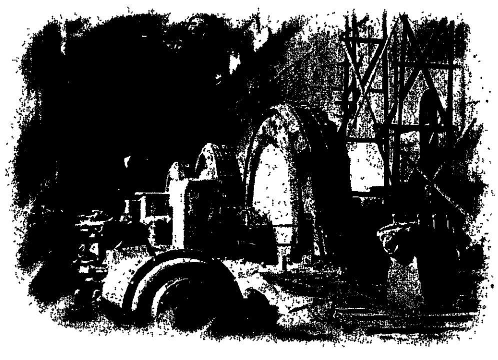


Fig. 80. The generator room at Untra during construction.

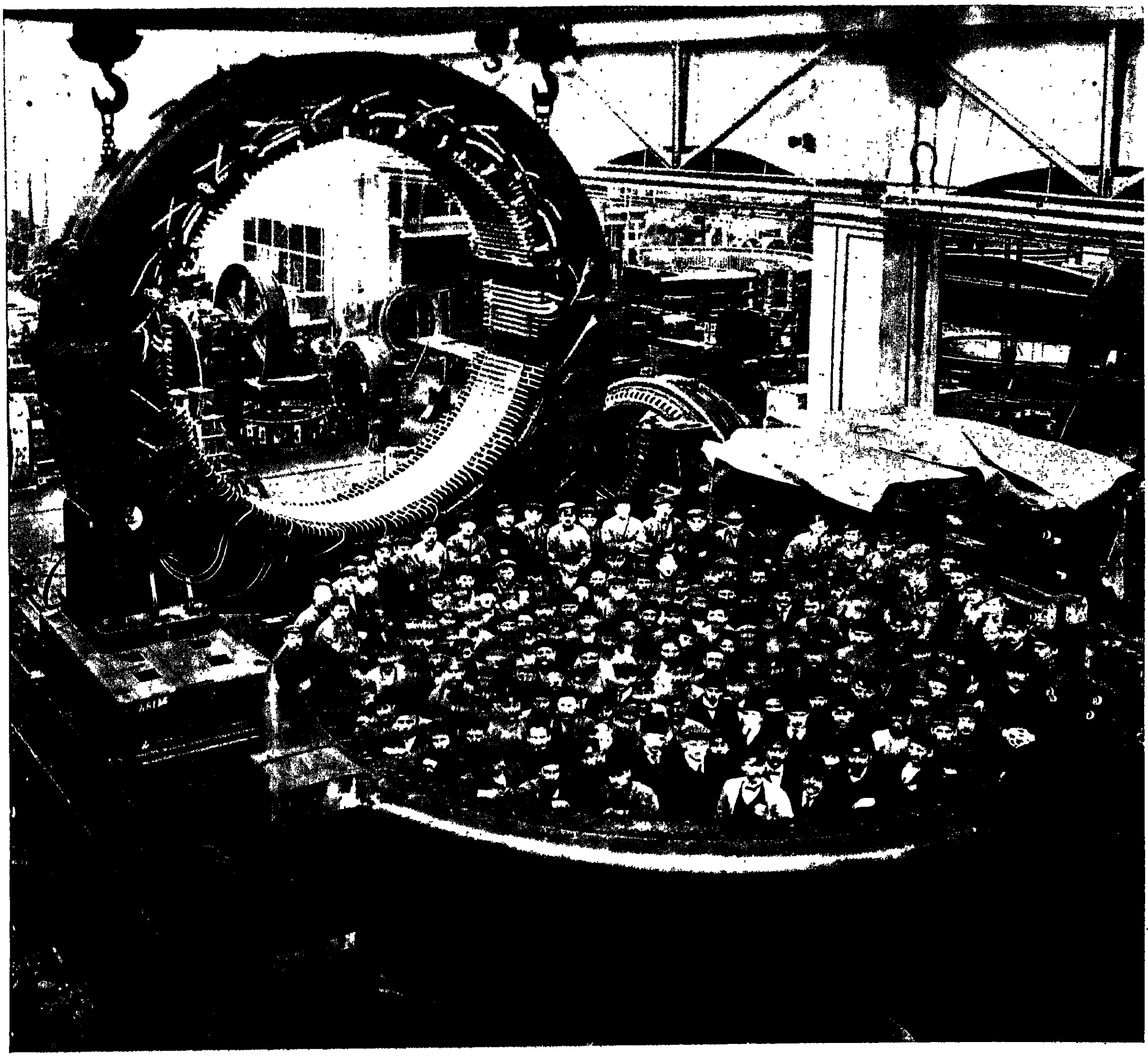


Fig. 81. 153 men in stator of one of the Untra generators.

head of 15.3 metres after extensive dam and water controlling devices had been installed, and with a water volume of about 250 cubic metres per sec. The available energy is utilized through five double turbines each for 10000 HP. The present installation is laid out for 50000 HP, plus the power required for auxiliary machines which is derived from a separate equipment. After submitting estimates Asea received an order for four three-phase generators to be delivered in 1917.

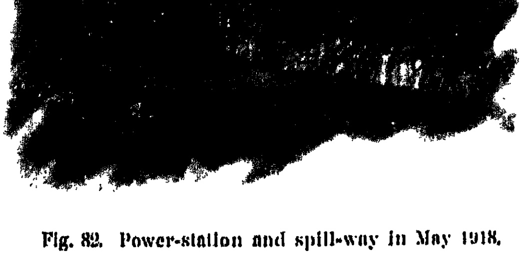


Fig. 82. Power-station and spill-way in May 1918.

Each generator is designed for a continuous full load of 9000 KVA, 6800 volts, 125 r. p. m., 25 cycles. They are of standard construction, *i. e.* stationary armature and rotating field on horizontal shaft. These generators differ from others of the same size in that they are only partially enclosed. This design was decided upon on account of the low speed, at which no unpleasant noise would be produced by air currents and also because the air needed for cooling could be taken from and discharged direct into the generator room without unpleasant results to the attendants. Cast iron shields are placed over the coils with removable inspection doors similar to those on the totally enclosed machines, with the exception that these guards only project beyond the stator coils, field coils and rotor ring. Fan blades are attached to the rotor ring which effectively cool the field coils, laminations and stator coils, the air passing thence to the stator frame which is specially designed to deal with the warm air. The lower part of the stator frame is totally enclosed to prevent warm air from the machines getting into the generator pit which latter is connected to the outside of the building through an adjustable air duct. Openings on top of the stator permit warm air to escape into the power house. These generators are of no special interest beyond their large size.

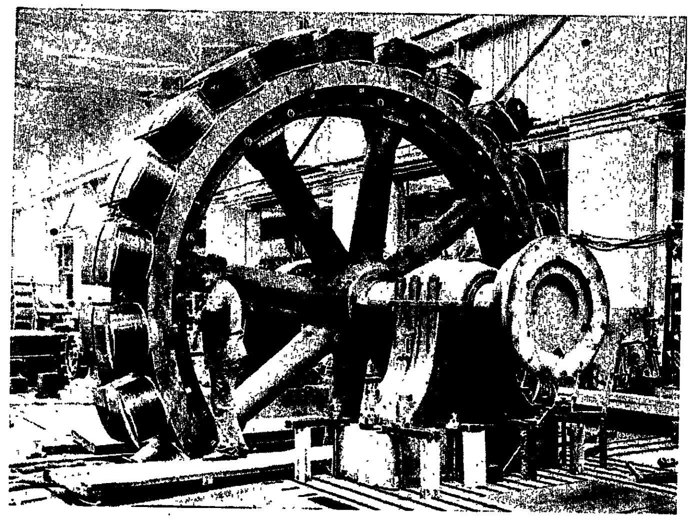


Fig. 83. Rotor of Untra generator.

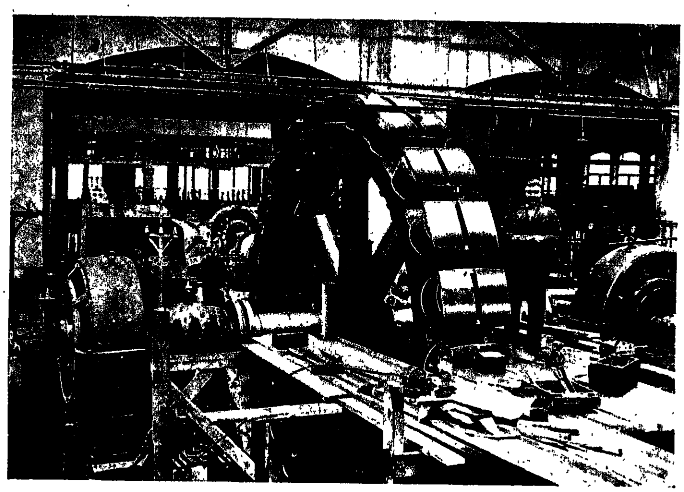


Fig. 84. Rotor and exciter of Untra generator being erected for testing.

The castings are iron, the stator frame being split horizontally: the greatest dimension across

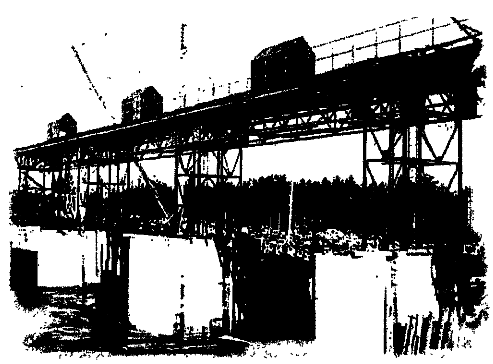


Fig. 85. Dam across lake Storgysingen, Untra.

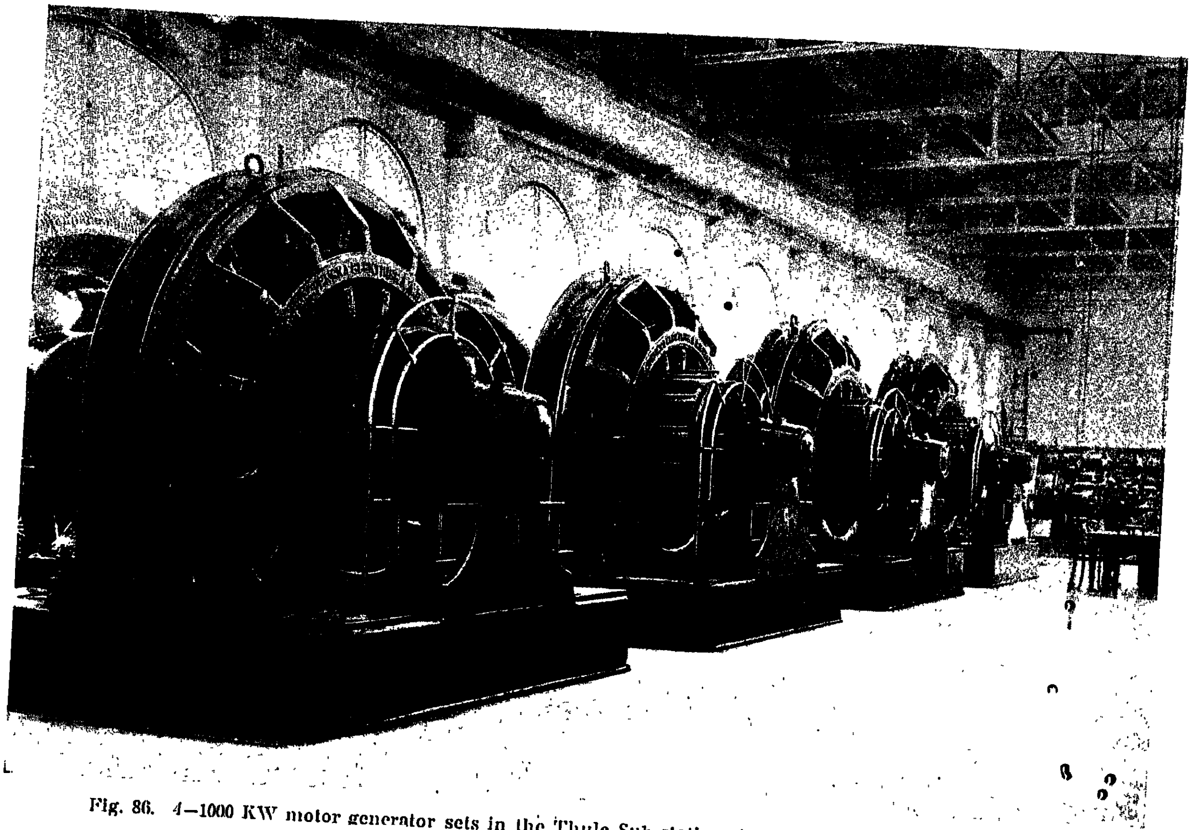


Fig. 86. 4—1000 KW motor generator sets in the Thule Sub-station, Stockholm City Electricity Works.

the feet is 8.5 metres, height 7.25 metres and total axial length including exciter is 6.05 metres. The laminations are arranged in the usual manner and have an outside diameter of 6 metres, inside diameter of 5.45 metres and are 0.75 metres wide. The winding is divided in five half open slots per pole per phase and the conductors consist of two bars connected outside the slots with copper connectors. This type of winding was selected owing to the fact that the voltage had to be stepped up for the transmission line to Stockholm, so that it was not material, within certain limits, for what voltage the generators were wound. The designers were able to fix on a winding which would ensure absolute reliability, easy inspection, cleaning and repair. Each bar is enclosed in a tube of insulating material, giving good insulation not only from the frame but also between bars: the winding is secured to brackets outside the laminations whereby a strong and rigid construction is assured with no danger of coils distorting under short circuits. The stator terminals are placed at the bottom of the frame, which is the most convenient position for connecting the generator to the cables from the switchboard to which they are led through the air ducts mentioned above.

Fig. 87. Spill-way from power station.

Fig. 88. Group of bearings for Trollhättan, Untra and other installations.

The 24-pole rotor is of cast steel and the poleshoes and polepieces divided into two parts bolted together with a space between, forming a channel for cooling air. The whole is shrunk on to cast steel hollow arms. The rotor is not designed according to Asea standard construction with polepieces and ring in one, but the polepieces are made separately and secured to the ring with bolts: this design was used to avoid splitting the ring, which, had the polepieces been cast on to it, would have been too large for transport by rail. The solid poleshoes are in one with the polepieces. The field winding, consisting of 115 ½ turns of copper strip on edge, is rather unusal in that it is designed for a working pressure of 440 volts.

The collector rings are located between the rotor and the outside bearing, and, contrary to usual practice, the connecting cables do not in this case pass through the shaft but are secured to its surface in the same manner as on small machines.

Each generator has its own exciter direct connected to the rotor shaft but with its stator mounted on an independent bedplate.

The shaft of the generator is furnished with a forged flange coupling for connecting to turbine and also

Fig. 89 The head-gates.

with a shaft extension for receiption of exciter armature, and is counterbored the full length. The flywheel effect of the rotating masses is approximately 1850000 kgms. The bearings are standard ring oiled, and water cooled.

The weight of each generator is approximately 150 tons, the stator weighing 56 tons, rotor 45 tons, bearings and bedplate making up the balance. The weight of the exciter is about 7.5 tons. From the generators current is taken through very simple and easily accessible switchgear to the transformers, which are three-phase, 6800—100000 volts, one transformer being installed for each generator. The higher voltage is used for the 130 kms transmission line to Stockholm, this being the highest voltage used in Sweden.

In Stockholm the transmission line is connected with the steam station at Värtan and the potential is stepped down to 6000 volts for use at the sub-station and in the distributing network.

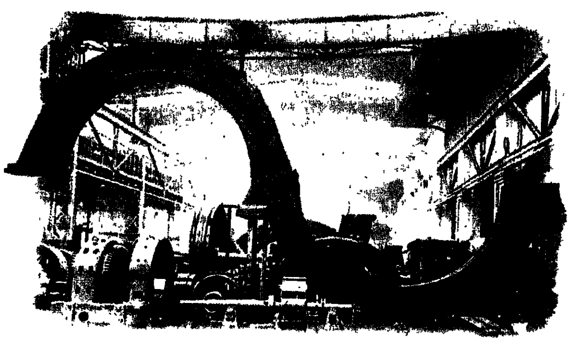


Fig. 90. Stator halves of Untra generator.

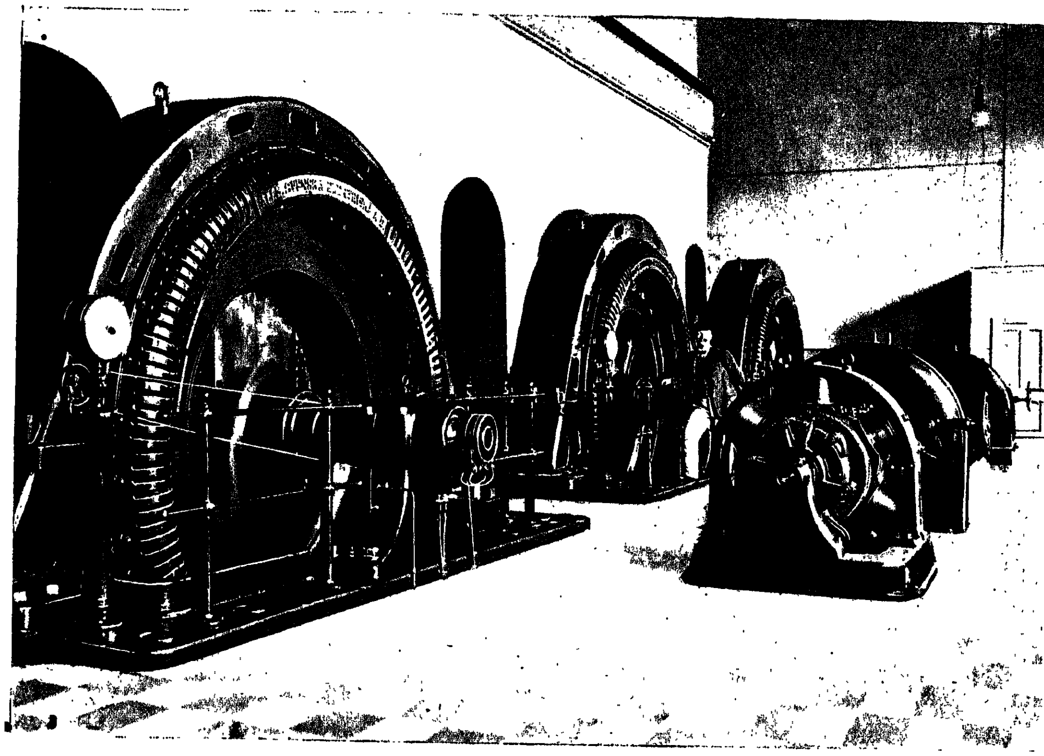


Fig. 91. Interior view of Yngeredsfors power station after first extension.

YNGEREDSFORS POWER COMPANY

THE Yngeredsfors Power Company was formed in 1904 to make use of the water power available in the Ätran River at Yngeredsfors, the Company having secured rights to extend and follow out the plans of the older Company. A proposal by the firm A.-B. Vattenbyggnadsbyrån, Stockholm, to erect a dam 8 metres high and 140 metres long across the river valley was adopted and completed during 1905—1906 whereby the head could be brought up to 18 metres. It was first proposed to build the Power Station some distance below the dam, but later the location was changed to the North West end. The station was laid out to take four units, of which three were installed at once, together with two turbine driven exciters. The turbines for the exciters are placed in vertical steel housings inside the power house.

Directly connected to each of the turbines is an Asea three-phase generator built for a continuous output of 2350 KVA, 4000 volts, 250 r. p. m., 50 cycles at 80 % power factor. These

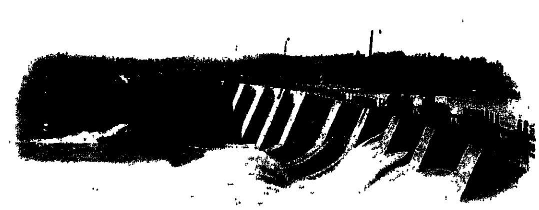


Fig. 92. Dam at Yngeredsfors.

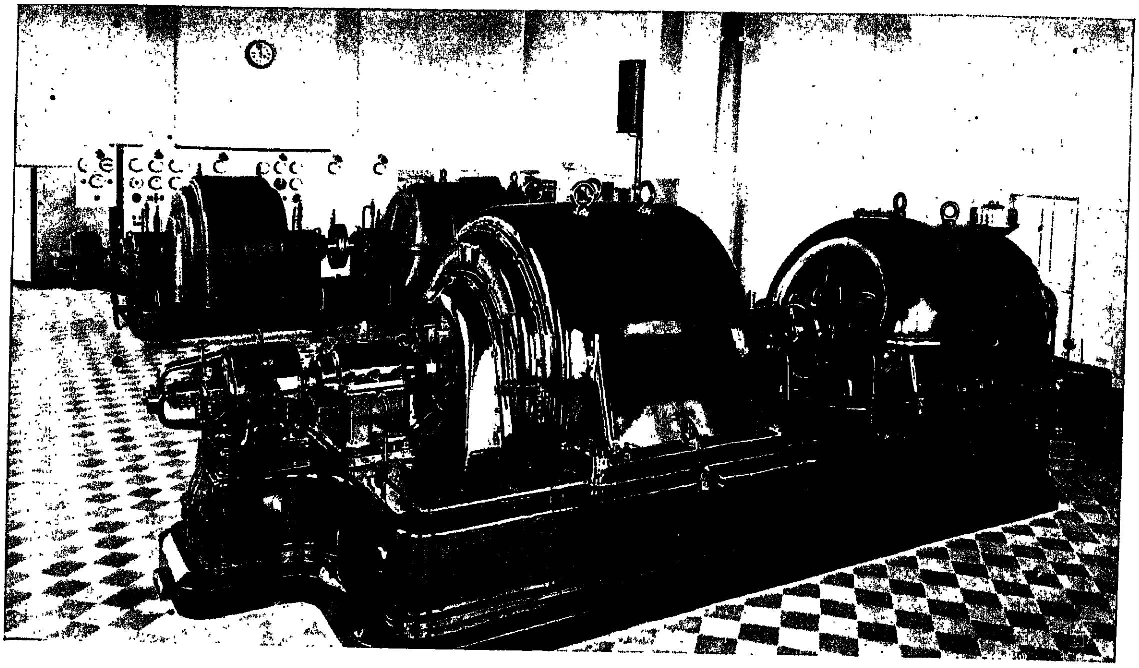


Fig. 93. Standby steam station at Varberg.

were ordered and designed in 1905, built during 1906, and erected in the power house in April 1907. Although at the time of erection these machines were amongst the largest built by Asea, compared with present day machines they would only be classified as of medium size. They are of the open type with rotating field, armature in stator frame of cast iron mounted on a cast iron bedplate, embedded in the concrete foundation. Largest overall dimension across stator feet is 5.45 metres, the length of shaft is 3.34 metres from the turbine flange to end of collector rings, which are beyond the smaller bearings; the centre line of shaft is 0.8 metres above the floor and the highest point on stator 2.94 metres above floor level. The armatures are standard construction with radial cooling ducts and have a three plane winding in partially closed slots. In accordance with standard practice at that time, the openings in stator frame were in the periphery, not on the cylindrical ends as now designed. The stators are split horizontally and have one detachable foot.

The rotors are made of Siemens Martin Steel, with polepieces and ring made in one, the poleshoes being secured with bolts. To obtain the necessary regulation in the turbines the flywheel effect of the generators was increased by an additional ring of cast iron secured to the rotors bringing up the GD^2 to 70000 kgm^2. The field windings consist of two coils per pole concent-

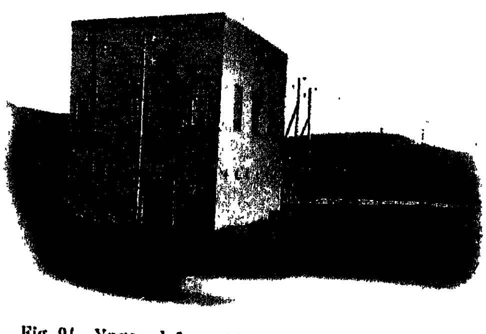


Fig. 94. Yngeredsfors—Mölndalslinjen tie-station at Veddige.

rically wound with copper strip on edge. The shafts are provided with a solid flange at one end for direct coupling to the turbines and the other end is counterbored to allow egress for leads from the field winding to the collector rings placed outside the bearing. The bearings are standard with ring lubrication. Total weight of each machine is about 40 tons, the stator weighing 16.5 tons, the rotor 15 tons, and the remainder in bearings, bedplate, etc.

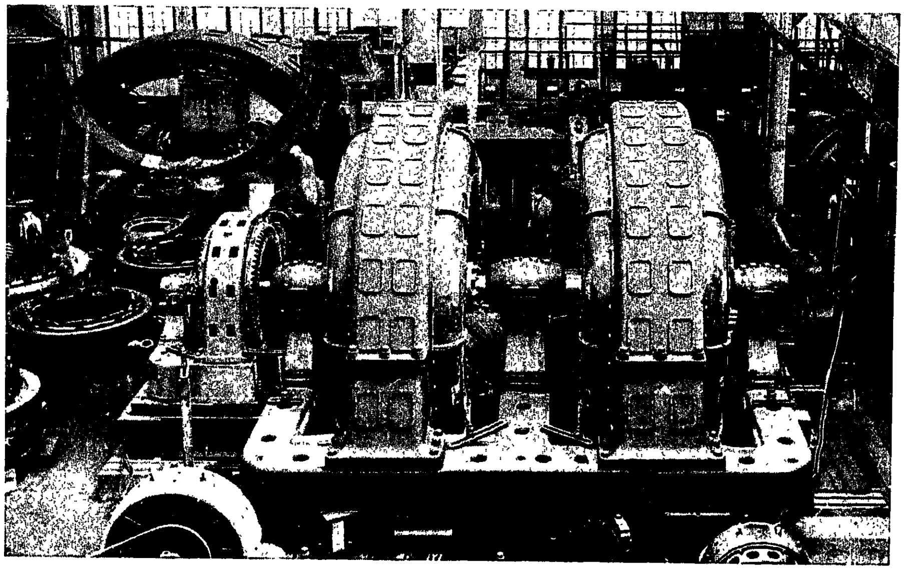


Fig. 95. Frequency changer for Mölndal in the test room for large machines.

One of these machines was shown at the Norrköping Art and Industrial Exhibition in 1906 and created much interest owing to its unusual size. The highest award in this class was conferred upon Asea for this exhibit.

In 1915, the time had arrived to complete the power station, and the fourth generator, also supplied by Asea, was installed. This machine was of the G type rated for a continuous output of 2850 KVA, 4000 volts, 300 r. p. m., 50 cycles at 80 % power factor. This generator like the older type has rotating field, and armature in stator frame, the latter of cast iron mounted on a cast iron bedplate embedded in concrete. Largest overall dimension across feet, 4 metres. From the turbine coupling to the extension carrying the exciter armature, the shaft is 3.05 metres in length. The centre of machine is 1 metre above floor and the highest point of stator 2.66 metres above floor level. The GD^2 of the rotating parts is 45000 kgm^2. In order to obtain such a large flywheel effect for this size of machine extra rings were fixed on each side of the field-coils, and these like the rest of the rotor are of Siemens Martin Steel. The weight of the machine is approximately 32 tons, of which 14.2 tons is in stator and 14.9 tons in rotor, the balance in bedplate, bearings, etc.

The terminal voltage of the generator is 4000 which is stepped up through Asea transformers to 40000 volts for the transmission lines also

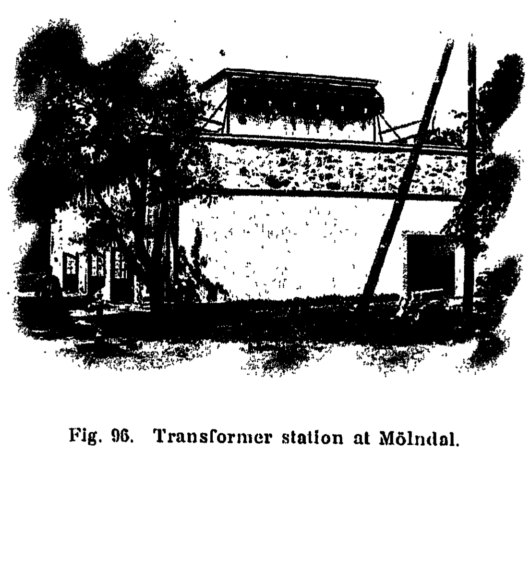


Fig. 96. Transformer station at Mölndal.

supplied and erected by Asea. Power is distributed through this network partly to agricultural districts, adjacent villages, and to the cities of Gothenburg and Varberg. In the latter town the power company has a standby station equipped with two steam turbines furnished by Asea. This station was originally built for one generator of 2340 KVA, 4000 volts, 1500 r. p. m., 50 cycles, which was delivered in 1907, but in 1911 it was extended to instal a second machine of 4350 KVA, 4000 volts, 3000 r. p. m., 50 cycles. Both of these machines were the largest of their kind manufactured in Sweden at that time.

In addition, Asea has supplied a frequency changing set for the power company's sub-station at Mölndal, close to Gothenburg; the motive of this was to be able to connect with either Trollhättan or Yngeredsfors stations, but as these are 25 and 50 cycles a frequency changing set was necessary.

This sub-station, apart from auxiliary machines, is equipped with two direct coupled synchronous machines direct connected to one starting motor which can be run from either system. Each synchronous machine can be run as motor or generator in order to take current from either system and deliver to the other. The set is designed for a continous output of 5000 KVA, 10000 volts, 375 r. p. m., 50 and 25 cycles at the lowest power-factor cos. $\varphi = 0.6$. Both machines are mounted on a common bedplate with one middle bearing, but apart from this each machine is self-contained. They are totally enclosed and provided with cold and warm air ducts. The rotors are fitted with fan blades which draw air from the machine pit, which is enclosed and fed by an air duct connected to the outside of the building. After the air has passed through the machine it is expelled through air ducts on each side of the lower half of the stator frame. With the exception of this feature the machines are built on standard lines having no details worthy of special mention. The total weight of the set including bedplate and starting motor is approximately 127 tons, of which the 50 cycle machine weighs about 47 tons, the 25 cycle about 64 tons, the remainder being allocated to the starting motor, etc. The rotating parts weigh about 37 tons and their flywheel effect (GD^2) is 135000 kgm^2. The shaft is carried by three water cooled ring-lubricated bearings with a solid flange coupling connecting the two short machines shafts together.

The set including the starting motor occupies a space of 8 metres axially, 6 metres wide, 3.37 metres high, and 2.2 metres below floor level. This set was installed during the early summer of 1917.

Fig. 97. Transmission lines crossing river at Veddige.

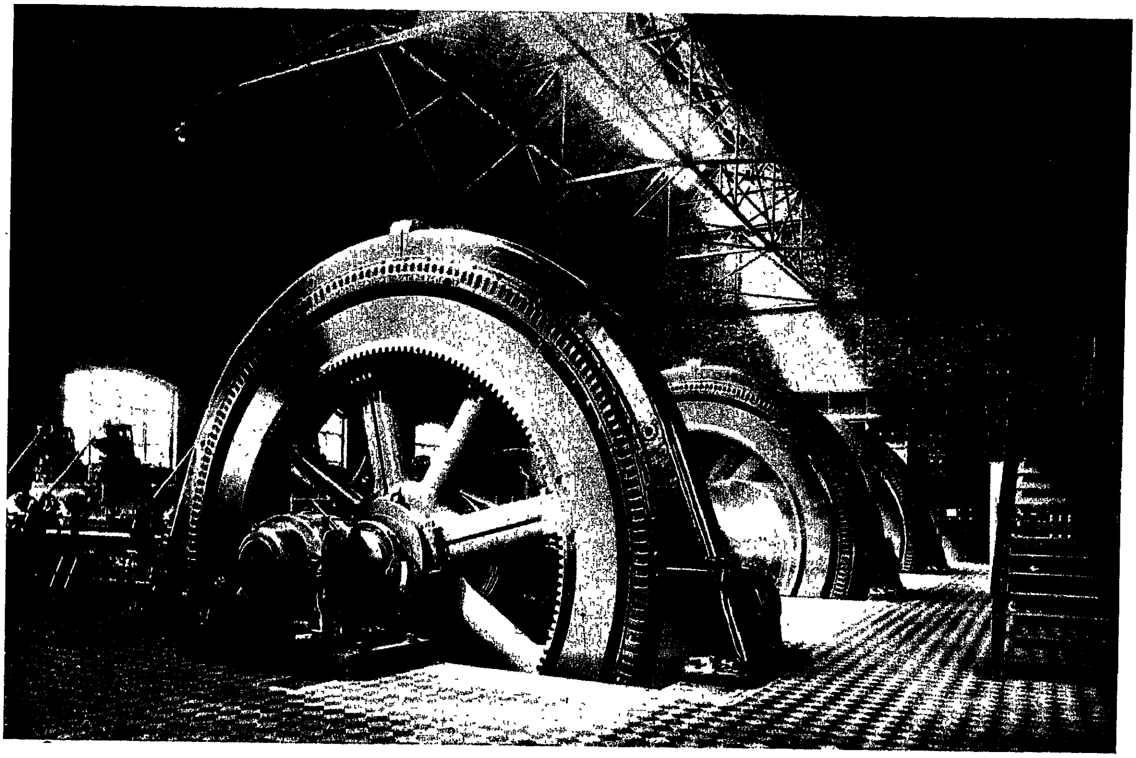


Fig. 98. Interior view of engine-room.

OXELÖSUND IRON WORKS COMPANY

IN all countries where Asea has installed large generators up to the present time, the conditions have been such that water power was available and utilized; as a result of this the majority of the large generators has been for direct coupling to water turbines. This has, however, not prevented Asea from securing orders for generators of other designs as shown by the installation at Oxelösund, and the supply of turbine driven sets which at the time of erection were the largest of their type then built. A description of this class of generator cannot be given in this book as it is primarily intended for slow speed machines. To this class can be added the three large three-phase gas engine driven generators at the Iron Works at Oxelösund which have recently been put into operation, and we herewith give a short description of same. The order for this installation was placed in the spring of 1914 and the machines were delivered in 1915. The order not only covered the 3 three-phase generators,

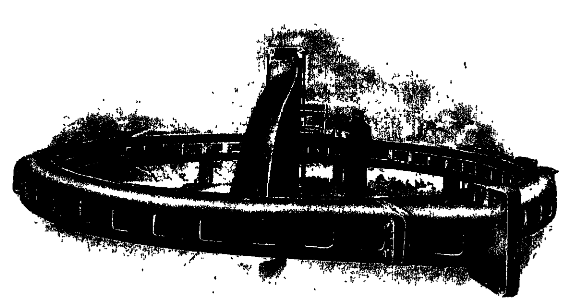


Fig. 99. Machining stator frame.

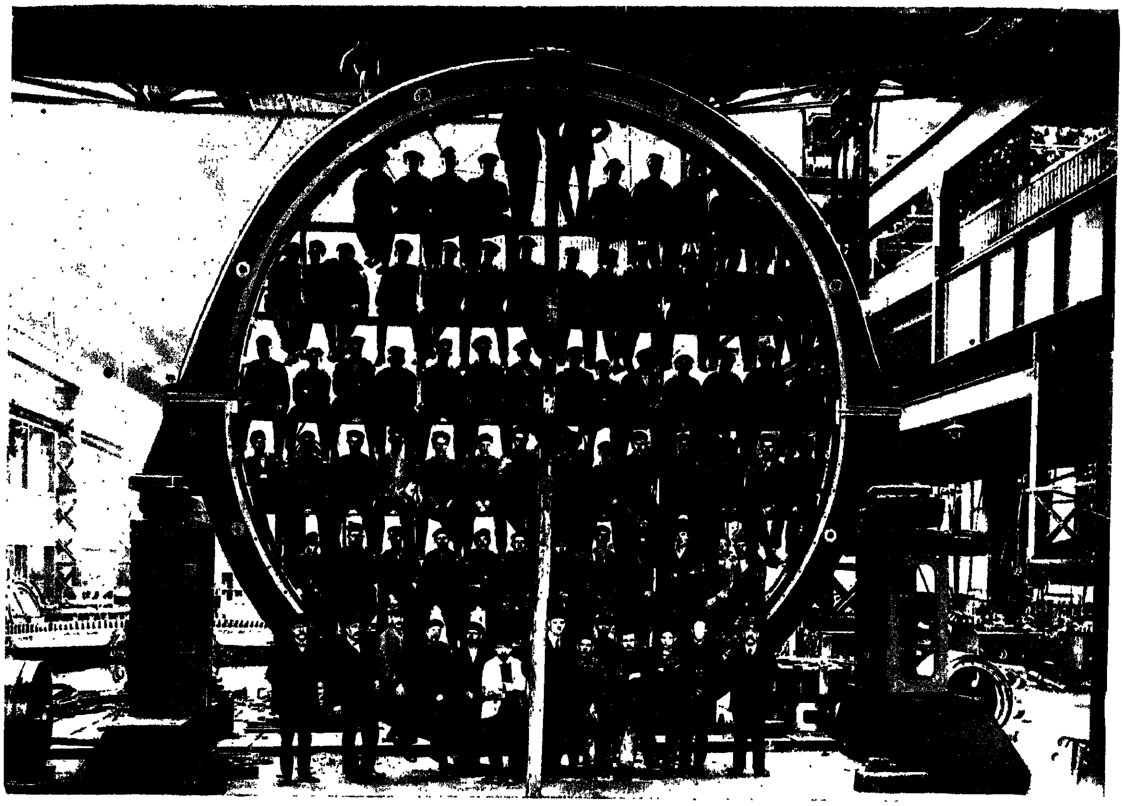


Fig. 100. Large stator frame.

exciters, switch-gear and auxiliary apparatus for the power station, but also the whole of the electrical equipment and auxiliary plant.

Each generator is designed for a continuous output of 1300 KVA, 3150 volts at 94 r. p. m., 50 cycles. The power generated is chiefly used in the Iron Works, but part is distributed for running smaller plants in and around Oxelösund. After the transmission lines of the big Älvkarleby power scheme were distributed over the province of Södermanland, they were connected to the Oxelösund system so that the gas engine station at Oxelösund Iron Works acts as a stand-by for the South Eastern area of the power company's system, in the same way as the steam turbine station at Västerås, takes care of the North Western area.

The generators are of the horizontal open type with rotating field and armature coils in stator frame. The shafts for these generators were not furnished by Asea, but by the gas engine builders who also supplied the bearings. As the cyclic irregularity of gas engines, (which in this case are driven by blast furnace gas) is bad, it was necessary to instal a heavy flywheel to give an even turning moment. In the early

Fig. 101. Flywheel half.

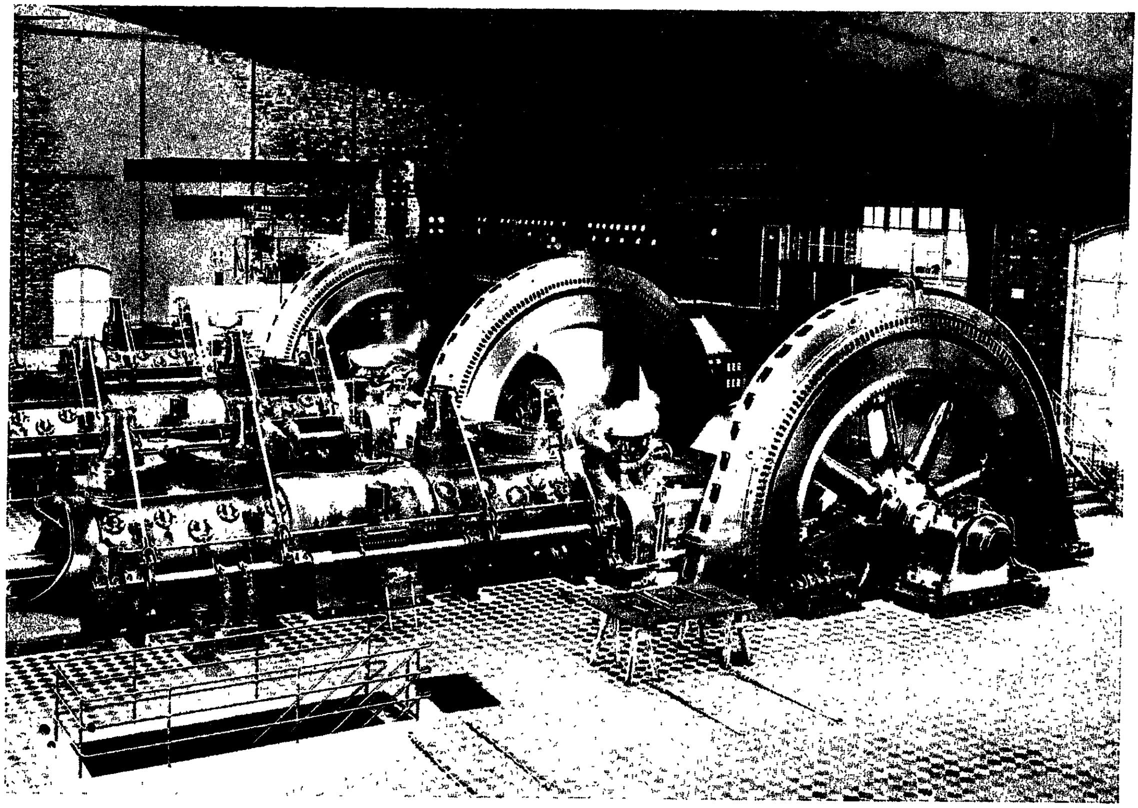


Fig. 102. The three generators showing flywheel construction.

days it was standard practice to equip a gas engine with a separate flywheel, but in this case the rotor was designed with a big flywheel effect to obtain proper conditions for parallel running. In consequence of this, the generators had to be built with a very large diameter to save excessive weight in the rotor, it being necessary to reduce the cyclic irregularity to 1/235. To secure this result a flywheel effect (GD^2) of no less than 1600000 kgm^2 was required, representing a kinetic energy of 1300 kgms per HP. These generators have the largest diameter of any built by Asea and across the air gap measure 6.8 metres, whilst the overall dimension across the feet is 8.8 metres; the vertical outside diameter of the stator frame is 7.88 metres and although they have a large diameter the axial width of the rotor ring is only 0.65 metre.

The stator is of standard construction with laminations dovetailed into the frame; the winding is arranged in two planes and occupies a great number of partially closed slots; the rotor has polepieces and poleshoes of forged iron, secured with bolts to the cast iron flywheel ring; the field winding is copper strip on edge.

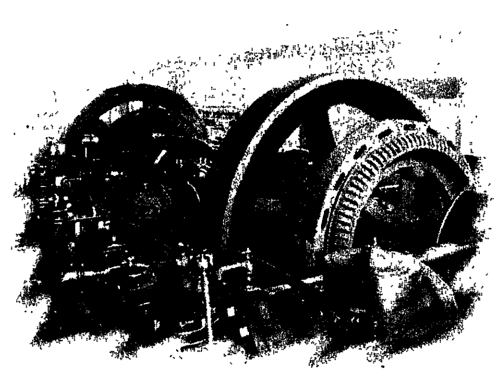


Fig. 103. Three-phase gererators driven by gas engines with separate flywheels.

Although the above mentioned cyclic irregularity of 1/235 was permissible in this installation, where the even running of the motors was not of such importance as for instance in the textile industry (where an irregularity greater then 1/300 is not permissible) it was decided to make all possible provision for good parallel operation between the generators, and to ensure this the poleshoes were provided with plain damping windings which proved advantageous.

To facilitate easy handling in the shops, and also during transport, the stator as well as the rotor was divided into four parts, bolted together. Some of the machining work had to be done with these sections securely connected together and could only be done in Asea's Works — thanks to the excellent shop facilities existing: it was a problem requiring careful consideration and preparation but was handled with the greatest credit to the shop management.

In the event of repairs being necessary all parts must be readily accessible and to effect this the stator is mounted on a base which permits of axial movement to clear the rotor windings. With this arrangement any part of the rotor or stator can be repaired without taking the stator frame adrift or lifting the rotor from its bearings; generally speaking this is advantageous but in a special machine of this nature such an arrangement becomes a necessity. Each generator weighs about 95 tons of which 18 tons is in the stator and 73 tons in the rotor without the shaft and the balance in the bedplate, etc.

The field current is supplied by an independent exciter, one for each machine belt driven from the main generator. Direct coupled exciters were not desirable in this case on account of the slow speed.

As the gas engines cannot be started without extraneous help each unit is equipped with a starting motor provided with pinion which meshes with a rack on the rotor and bars the gas engine round until a charge of gas has been drawn into the cylinders, when the engine starts and automatically disengages the starting motor.

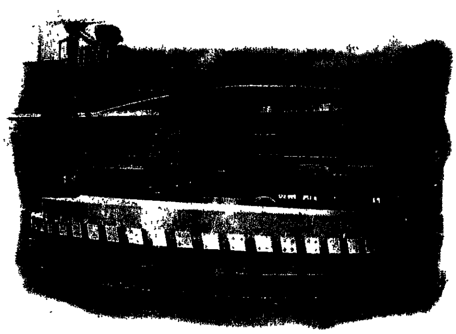


Fig. 101. Machining rotor.

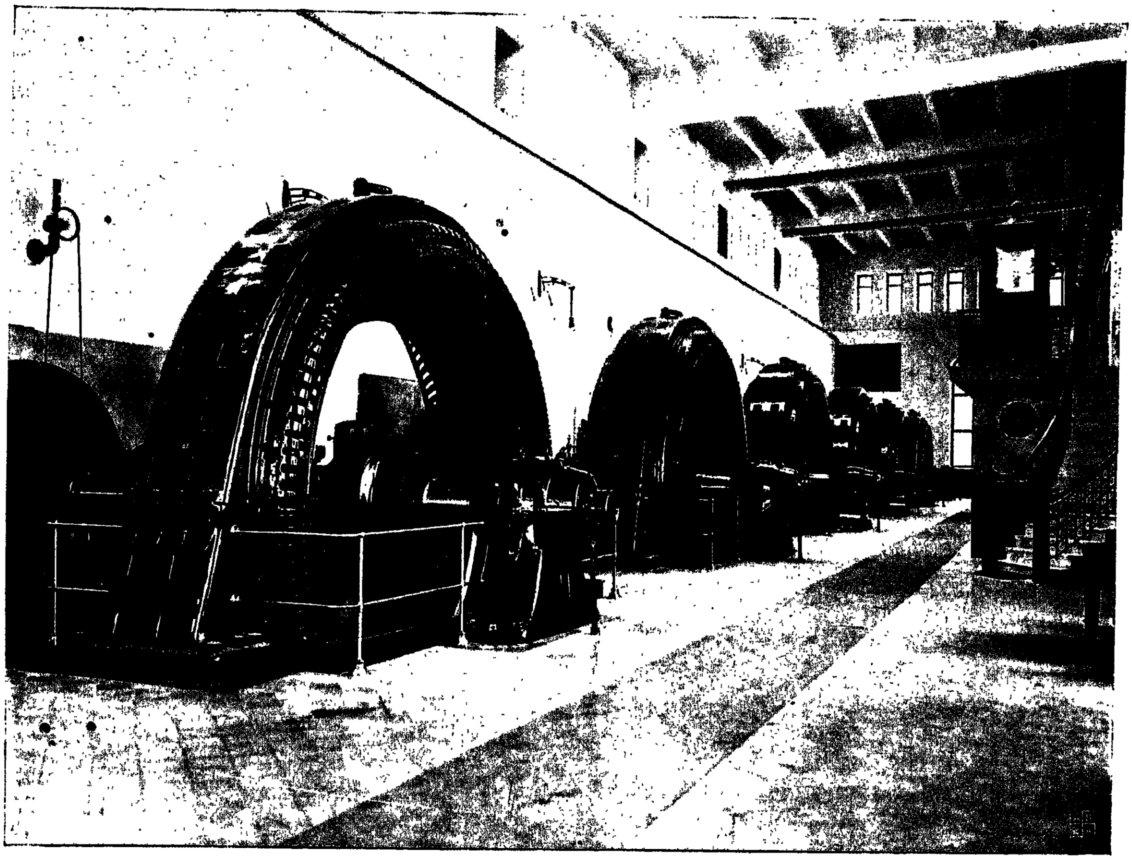


Fig. 105. Interior of Bullerforsen power station after final extension.

STORA KOPPARBERGS BERGSLAGS COMPANY

FOR the various installations of this company — one of the oldest and largest in Sweden — Asea has had the pleasure of supplying electrical equipment of the most varied types, the most important of which is the hydro electric station at Bullerfors on the river Dalälven.

The first contract in connection with this station was placed with Asea in 1908, but owing to various reasons (one of which was the general strike in 1909) the work was not completed until the spring of 1910. This installation consists of 3 three-phase generators each of 3500 KVA, 7000 volts., 180 r. p. m., 60 cycles together with field regulators.

This order was followed by a second one in 1912 for one more generator but of a larger capacity

Fig. 106. View of power station and dam at Bullerforsen.

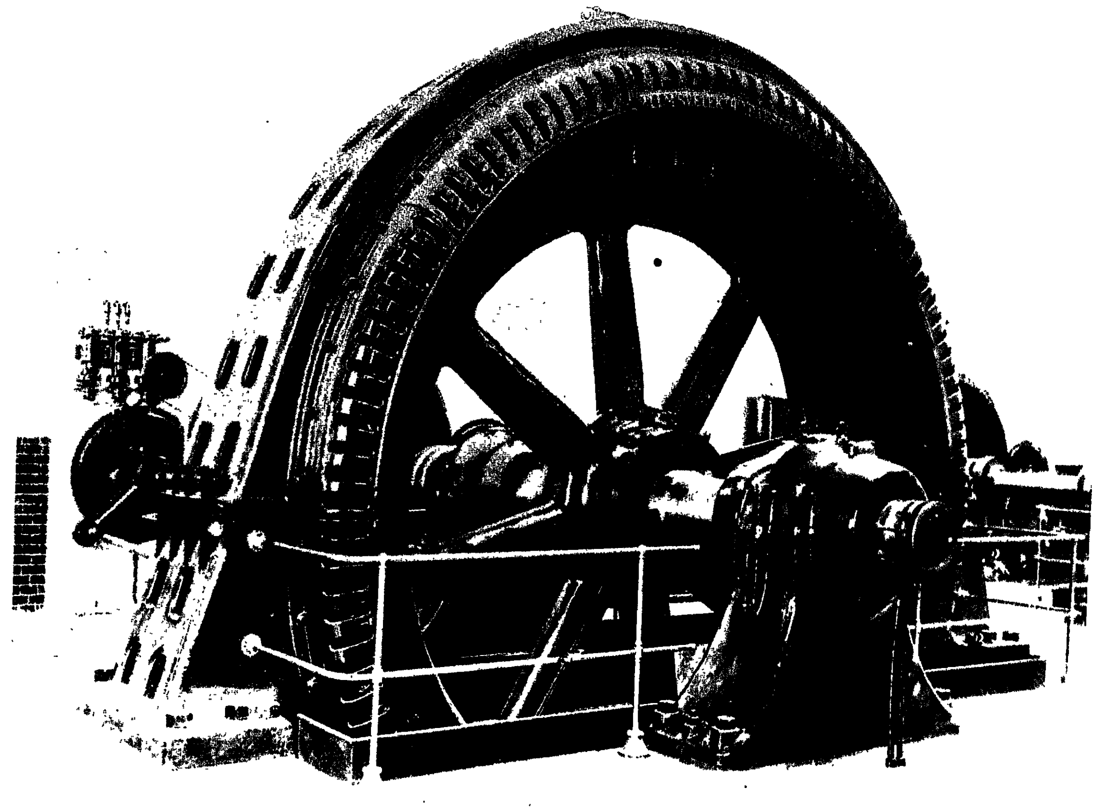


Fig. 107. 3800 KVA three-phase generator in Bullerforsen power station.

viz. 3800 KVA. Later during the same year Asea received a further order for two more generators of the same output as the last one supplied, this completely equipping the station with generating units. These three generators were erected during the latter part of 1913 but not immediately put into service by the purchaser: the last machine was put in commission in February 1914.

The specification for the first three generators called for a 10 % continuous overload "without dangerous heating". The generators were so liberally designed that they could stand 10 % continuous overload and still be within the temperature limit specified for full load, and an additional 10 % could be added to this without the temperature rising sufficiently to endanger the insulation. The orders for the additional generators were based on this, consequently the specification called for a contionuous output of 3500 KVA plus 10 % or about 3800 KVA with an overload of 10 % without dangerous heating.

Fig. 108. Dam and power station at Bullerforsen.

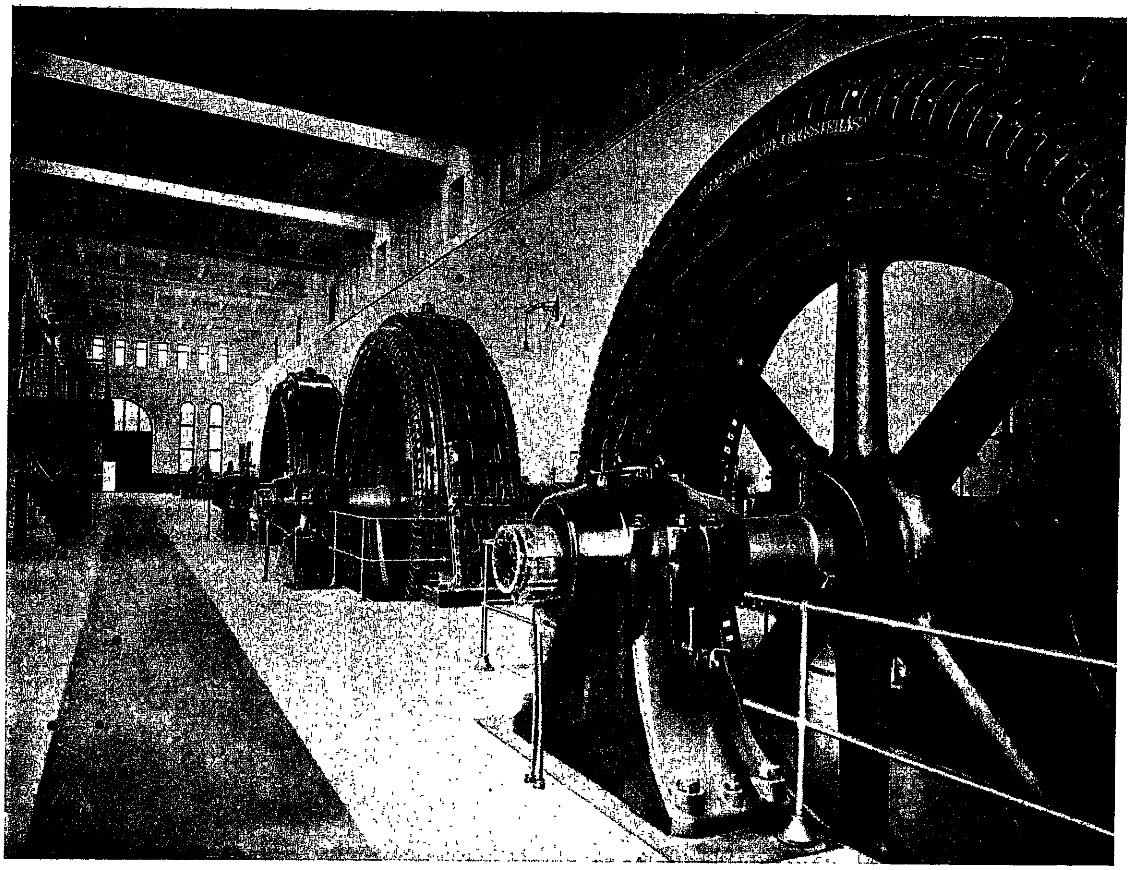


Fig. 109. Interior of Bullerforsen power station after first extension.

The three original generators were also run at 3800 KVA, giving the station a total capacity of 22800 KVA. One of the reasons for raising the rated capacity of the generators was, that after some time the water supply was found to be more favourable than at first anticipated.

The bulk of the power generated is used in the Company's iron works at Domnarvet, partly for driving mills of which one installation is of special interest, this consisting of an Asea direct current reversible motor rated at 3600 HP (maximum 9200 HP at 60 r. p. m.) driving a universal rolling mill, and partly for electrometallurgical work, furnishing power to electrical furnaces of the Helfenstein type.

The six generators are identical, of the open type with rotating field, stationary armature and horizontal shaft with solid flange coupling for bolting to the turbine shaft. These generators were among the first of the new large generator series built by Asea. The stator frames — split horizontally — are of cast iron

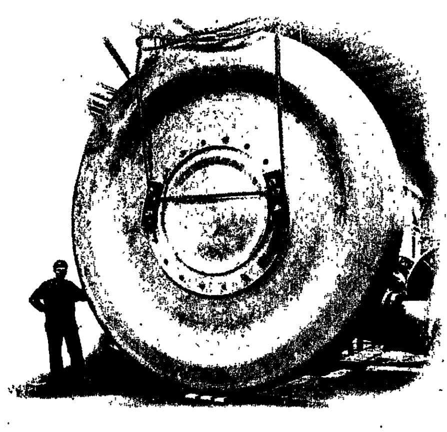


Fig. 110. Flywheel of motor generator set for reversing rolling mill motor at Domnarvet.

provided with a number of ventilating holes on the periphery. The laminations are secured in the usual manner by dovetailing to the frame and held together by heavy flanges, the bolts for same being placed near the outer edge and as far away as convenient from the magnetic flux. The laminations are divided into sections with radial cooling ducts between, and have 360 slots for the reception of the coils. The whole of the stator windings are insulated from the frame by staggered micanite tubes; the free ends of the coils are protected against mechanical injury by cast iron end shields. The three-plane type of winding was selected to obviate splitting the coils at the division line of the generator frames.

The rotors are of standard construction of Siemens-Martin Steel with polepieces and polering in one. For the regulation of the turbines the necessary flywheel effect is obtained by providing heavy iron rings cast in one piece with the arms of the rotors, over which steel rings are shrunk. The field windings consist of one layer of copper strip on edge, insulated and held in position according to Asea's standard construction. The flywheel effect of the rotor is 1000000 kgms.

As is customary in the older type of generators, the collector rings are placed outside the bearings and the shafts are bored for about half their length in order to bring out the connections from the field windings. In later types this style of construction has been abandoned, partly because it made the shaft so much more expensive. It was also found difficult to make a permanent and satisfactory job of the insulation where the cables entered the shafts, and experience proved it to be just as easy to supervise the rings and brush gear when located inside the bearing, as they require very little attention.

The floor-space, taken by each machine parallel with the shaft, is 4.35 metres measured from the flange of the turbine to outside of collector rings: the overall dimension across feet is 6.1 metres and from floor level to highest point of stator 3.6 metres. The centre of the machines is 1.025 metres above floor level and the depth of generator pits 1.7 metres. Neat wrought iron hand rails are placed round the generator pits and the generator room is very attractively furnished; in fact the whole power station is one of the best arranged and equipped that has been built.

The weight of a complete machine is 61.5 tons of which the stator weighs 28 tons, rotor and shaft 23 tons with the remainder in bedplate, bearings, etc.

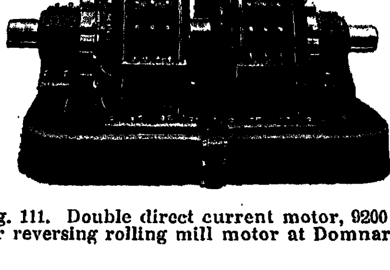


Fig. 111. Double direct current motor, 9200 HP for reversing rolling mill motor at Domnarvet.

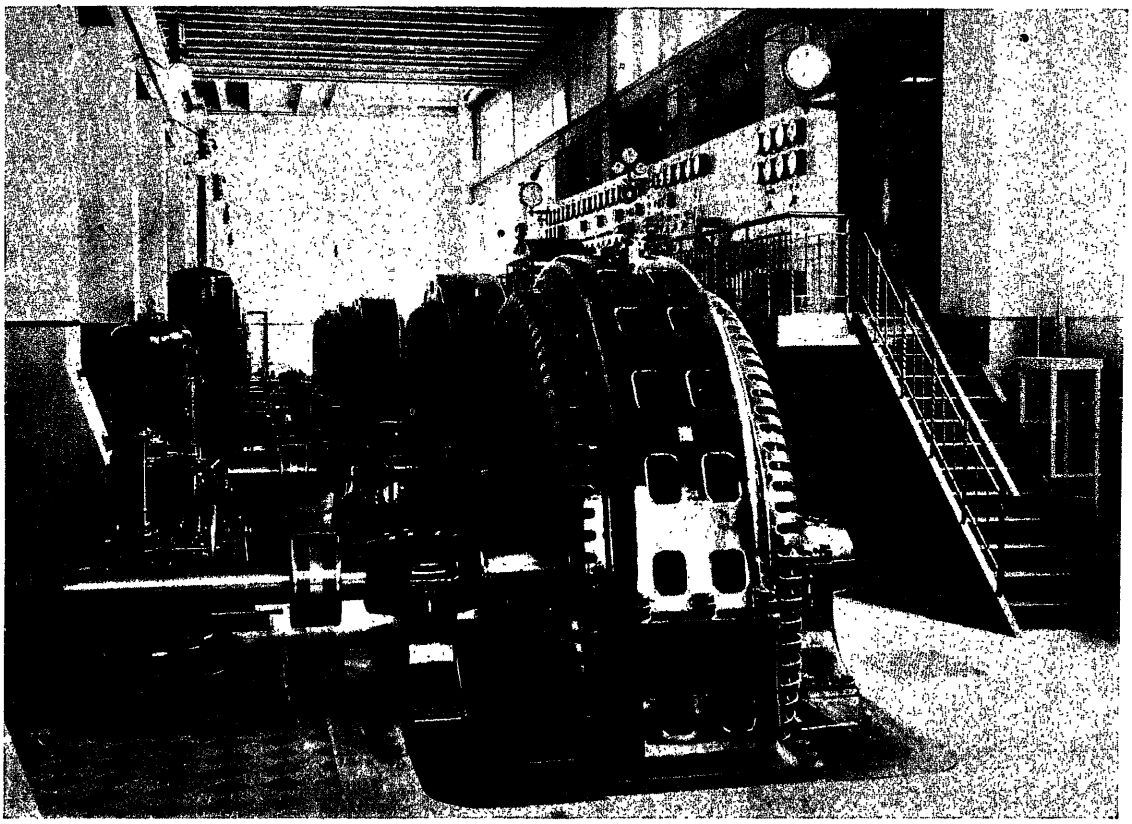


Fig. 112. Interior of Gullspång power station after final extension.

GULLSPÅNG—MUNKFORS POWER COMPANY

ASEA contracted with this company as early as 1906 for the construction of the electric equipment required for the contemplated power station, but owing to its large size, it took a considerable time to complete; in consequence of this it was not until the late summer of 1908 that the plant was started up and commenced to supply power, and by the early autumn the station was in continuous service.

The contract called first for 3 three-phase generators of the then standard "V" type, each of 3500 KVA, 5000 volts, 250 r. p. m., 50 cycles, and two exciters each capable of supplying three generators, together with all switchgear for the 5000 and 40000 volt system and transformers for stepping up from 5000 to 40000 volts. The following year Asea received a further order for one more gene-

Fig. 113. Exterior view of power station.

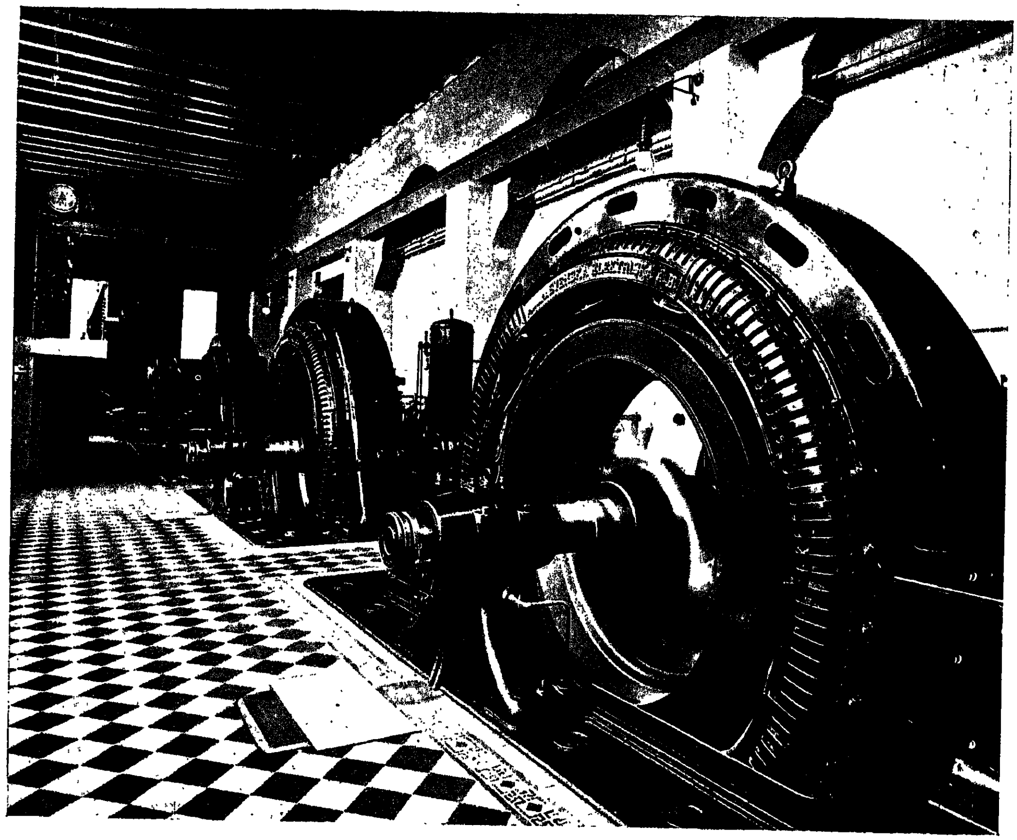


Fig. 114. Gullspång generator room 1910.

rator but somewhat bigger, of the same "V" type output 3950 KVA, 5000 volts, 250 r. p. m., 50 cycles, also a transformer of the same capacity together with the necessary switchgear.

In 1915 it was decided that the company should connect up with the State power station in the Province of Västergötland, and Asea received an order for the necessary machinery with switchgear to be installed in the substation at Lidköping. This consisted of a frequency changing set made up of one 25 cycle, three-phase synchronous machine and one 50 cycle machine — both Asea's standard G type rated at 3750 KVA, 3000—3300 volts, 300 r. p. m., with direct coupled exciter; also transformers for stepping down the line voltage from 50000 volts at 25 cycles to the motor potential of 3000 volts, and for stepping up the generator voltage from 3000 to 40000 volts on the 50 cycle side, together with complete switchgear.

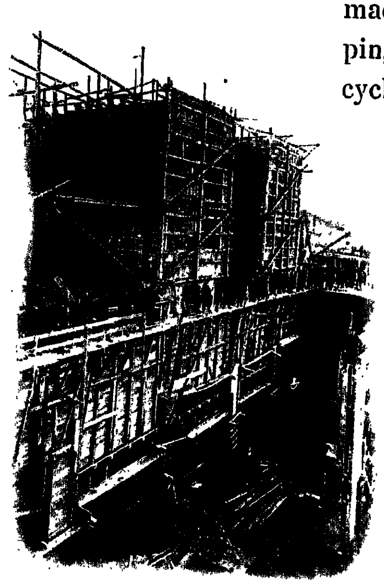


Fig. 115. Power station during construction.

The following year the power company decided to instal an additional generator at Güllspång for which Asea received an order in the spring of 1916 this covering a three-phase machine of the standard G type having a capacity

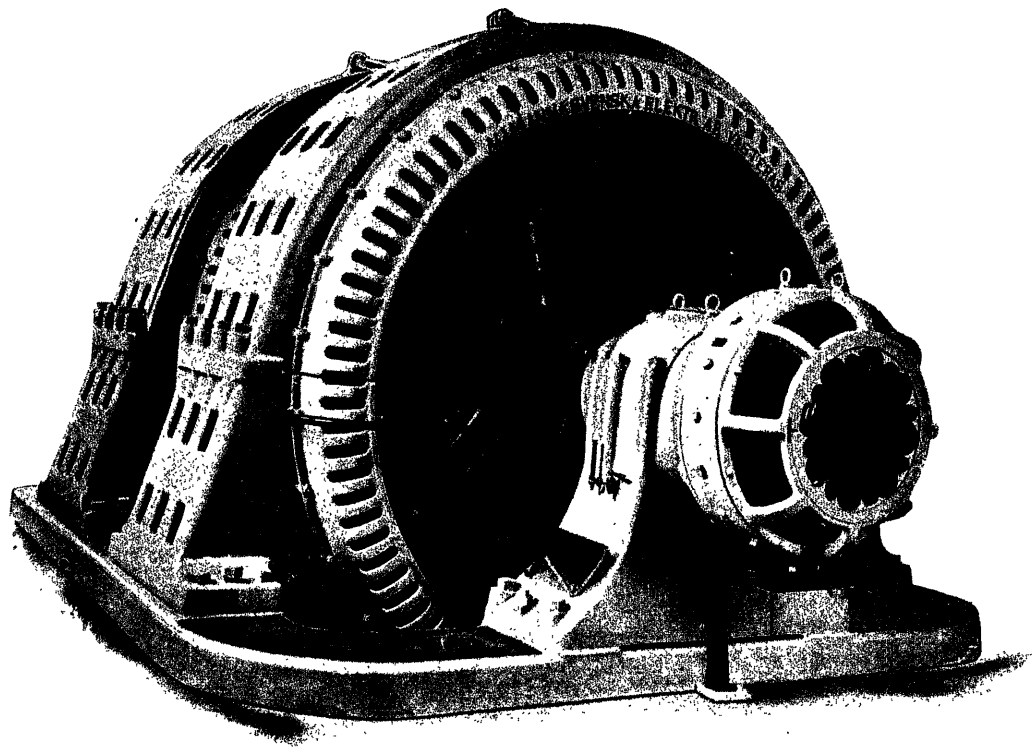


Fig. 116. Frequency changer at Lidköping.

of 3950 KVA, 5000 volts, 250 r. p. m., 50 cycles, also complete switchgear; the machine was put into operation in the spring of 1917.

The first generators delivered to Gullspång are, as already mentioned, of the "V" type 3500 KVA, 5000 volts, 250 r. p. m., 50 cycles, constructed with stationary armatures, rotating fields on horizontal shafts with solid couplings for connecting to turbines. The stator frames are made without openings at the ends but have rectangular openings in the periphery as outlets for warm air. Laminations and windings are arranged in the usual manner, the latter made as a three plane coil winding, is divided into 216 semi-closed slots and insulated from frame by means of seamless micanite tubes. The winding is protected from damage by standard cast iron end-shields.

To obtain the requisite flywheel effect for turbine regulation, the rotors are fitted with a large ring made in two sections, the outer section being of Siemens Martin Steel with the polepieces in one with it shrunk on the inside cast iron ring. The cast iron rings are widened and carefully machined to take the steel rings; the GD^2 of the rotors is 97000 kgm^2.

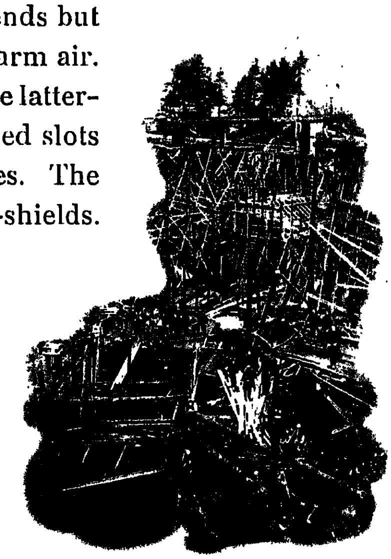


Fig. 117. Excavations for foundations.

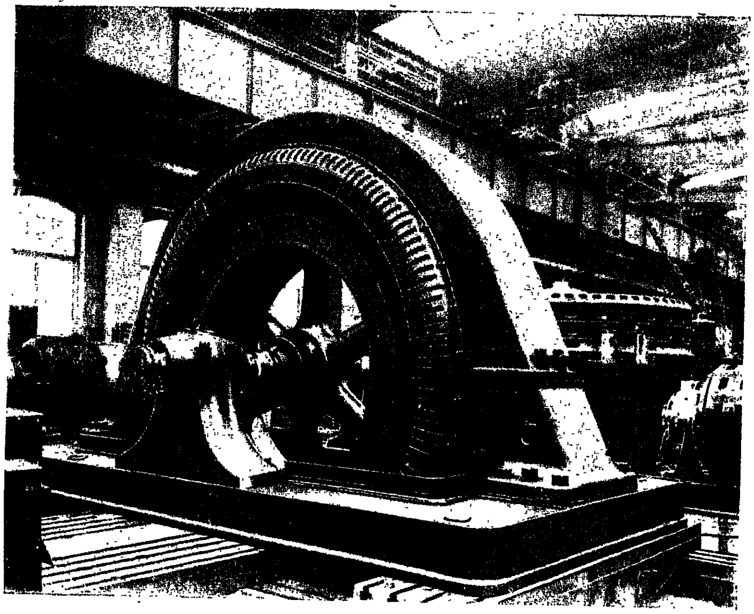


Fig. 118. 3950 KVA generator delivered in 1909, erected for testing.

The field winding of copper strip on edge in two concentric layers is held in position by solid pole-shoes bolted on to the polepieces. The shafts are bored to take the connecting leads to the field winding, and the collector rings placed outside the bearing. The overall length of the machines from turbine flange to collector rings is 3.75 metres, and overall width 5.45 metres; from the floor level to highest point of stator is 2.9 metres whilst the centre line is 0.75 metre above floor and the depth of the generator pit 1.65 metres.

The station has an air duct system to supply cooling air, taken from the outside and discharged into the machine pits; the warm air escapes from the machines direct to the power house.

The generator ordered the year after and rated at 3950 KVA, 5000 volts, 250 r. p. m., 50 cycles, is in general dimensions the same as the machines already described, but owing to its larger capacity has somewhat different windings and laminations.

When the Gullspång power station was started in 1908 it was with its capacity of 14450 KVA the largest power station in Sweden, remarkable at that time, not only for its aggregate but also for the size of the individual machines. These were the largest three-phase generators then installed in Sweden, also the transmission line and voltage were the maximum then in use. The power lines run from Gullspång North East to Örebro — where they are connected to the Örebro Electric Company's power system in a transformer station outside the town — and South West to Lidköping with several branch lines West and South.

In the latter town a connection will be made with the state power system at Trollhättan. The normal pressure of the Gullspång system is 40000 volts.

At the time the power station was built provision was made for extensions, which were carried out in 1916—1917 when a new machine was installed. This was of 3950 KVA, 5000 volts,

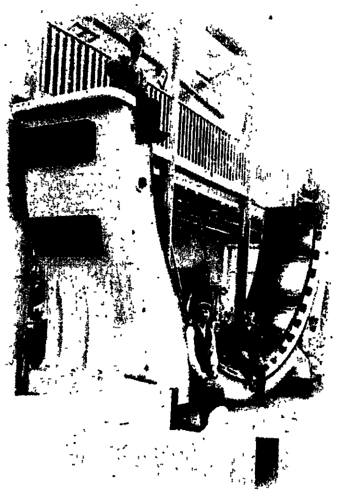


Fig. 119. Pattern for stator half of large AC generator.

250 r. p. m., 50 cycles. The generator, which is now known as type G is erected on its own bedplate, built with a stationary armature, and rotating field on horizontal shaft. This machine unlike the older generators, has air opening on the cylindrical face of the stator frame as shown in Fig. 120 which allows the warm air to escape radially and not parallel to the shaft as in the older types. (See Fig. 118). The armature winding is arranged in two planes and the coils are wound in 216 half open slots insulated in the same manner as the former types.

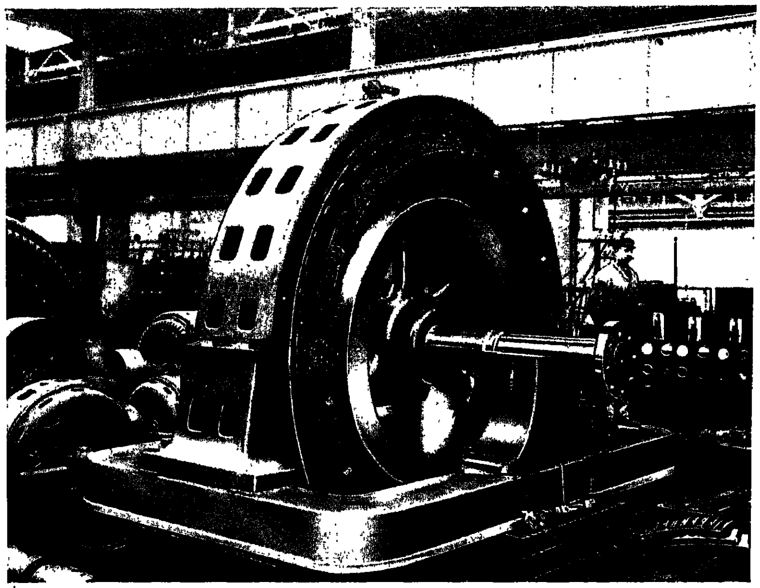


Fig. 120. 3950 KVA generator delivered in 1916, erected for testing.

The flywheel effect of the rotor is relatively large, (GD^2) — 103500 kgm^2 and the rotor is designed with two rings, the outer made of Siemens Martin Steel with the polepieces in one piece with it and the inner made of cast iron in one piece with the spokes and hub. The steel ring on this rotor is of the same width as the castiron ring, making a flush finish on both faces. The field winding is copper strip on edge, one layer per coil, held in place in the same way as on the first generators mentioned above. The collector rings are placed between the bearing and rotor, the shaft is provided with a solid flange coupling for bolting to the turbine. The overall length of the machine is 3.57 metres from the turbine flange to outside bearing. The width is 4.7 metres which is the greatest overall dimension; from floor level to highest point on stator frame is 2.83 metres and the generator pit is 1.6 metres deep.

The weight of the machine is 45.4 tons, of this 18.2 tons in the stator, 23.3 tons in rotor and shaft, and 3.9 tons in bedplate, bearings, etc.

To be able to connect up to the Trollhättan system a frequency changing set was installed in Lidköping, as previously mentioned. The generator (type G) stator is designed so that all outside demensions are identical with the motor, thus giving the set a more symmetrical appearance. This set is constructed with two bearings, the stators being placed close together on one bedplate.

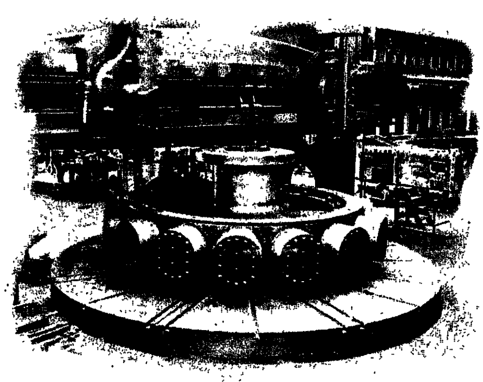


Fig. 121. Rotor for large AC generator being machined.

The inherent disadvantage in cooling is compensated for by having radial cooling ducts in rotors which project a powerful air current on the centre of the stator windings. The result of this is that the temperature rise of the generator is considerably below specification. The rotor is made of Siemens Martin Steel, field coils are wound with copper strip on edge in one layer, and the rotor ring and polepieces are cast in one piece. The field current is supplied by an exciter fixed to one of the bearing pedestals, with the armature pressed on to the generator shaft extension. The arrangement of direct connected exciter was convenient as the motor is a synchronous machine and excitation is not required until it is up to speed. Power has always to be delivered from the Trollhättan system to Gullspång.

With regard to the motor, it might be of interest to mention that it is the largest synchronous motor in Scandinavia.

The whole set is erected on a common bedptate, the two rotors are on one shaft with two bearings, which are water cooled and ring lubricated. One of the bearings is insulated from earth to prevent parasitic currents and the water pipe of the cooling system is cut and an insulating piece inserted at the break.

The overall length of the machine is 5.93 metres including exciter, 4.6 metres outside stator feet and 2.95 metres from floor level to highest point on stator frame. The pit is 1.10 metres deep, and is connected with the outside of the building by a duct arranged to allow the cooling air to enter at the centre of the machine.

The weight of the complete set is 82.5 tons — of this the generator weighs 32.3 tons, the motor 35.6 tons, the balance being in shaft, bedplate, bearings, exciter, etc.

Fig. 122. Discharge at horn gaps.

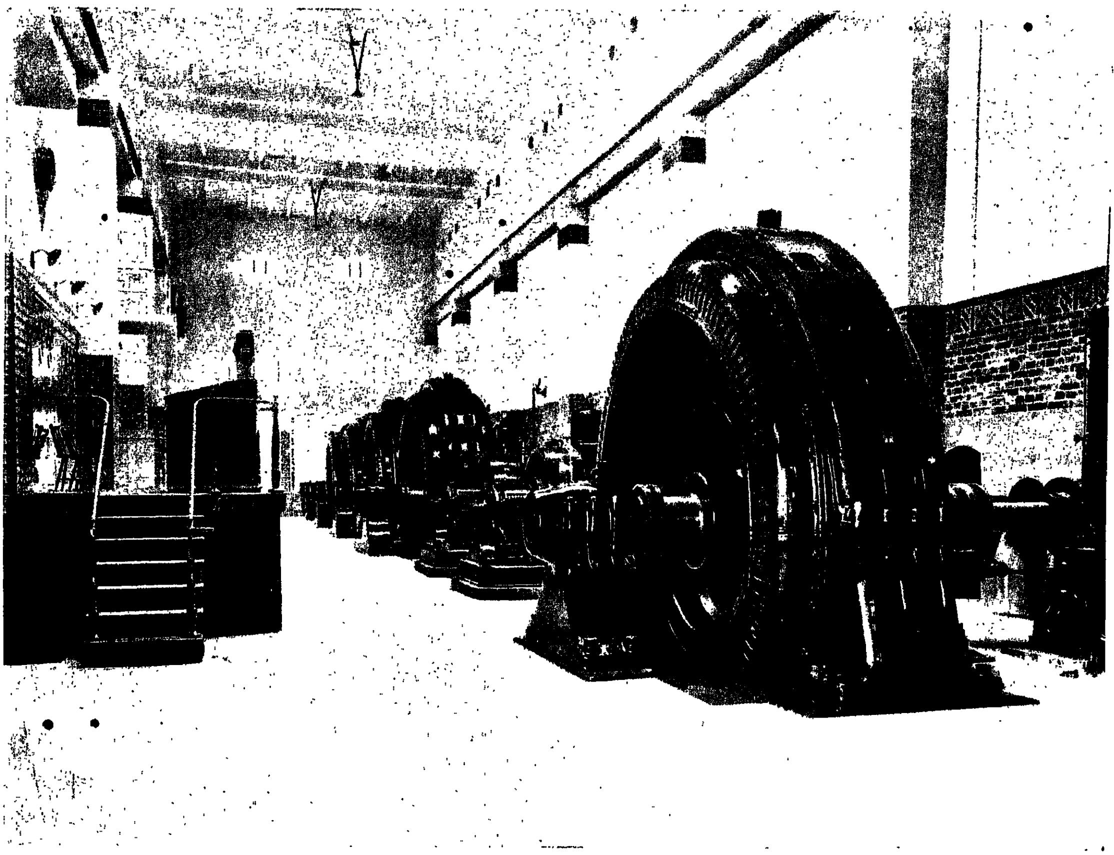


Fig. 123. Forshultsforsen power station.

UDDEHOLM COMPANY

THIS Company was one of the first in Sweden to produce pig iron ore on a large scale by means of electric blast furnaces, and has now, after exhaustive experimental work demonstrating the practicability of this system, several electric blast furnaces, installed at these works at Hagfors in the province of Värmland.

To furnish power for this and other electrically operated plants, it was decided as early as 1906 to develop the company's water power at Forshultsforsen on the River Klarälven. As the demand for power was not very great at first, it was decided that only part of the aggregate 20000 HP should be developed, but the dam and buildings were constructed to deal with the total power available.

In the spring of 1910 Asea received orders for

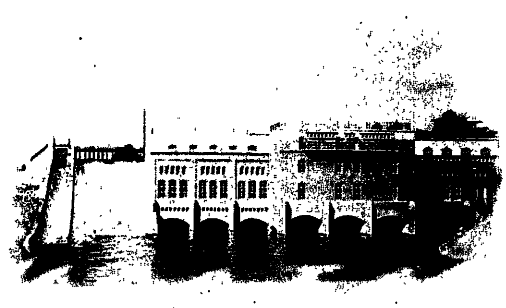


Fig. 124. Exterior view of power station.

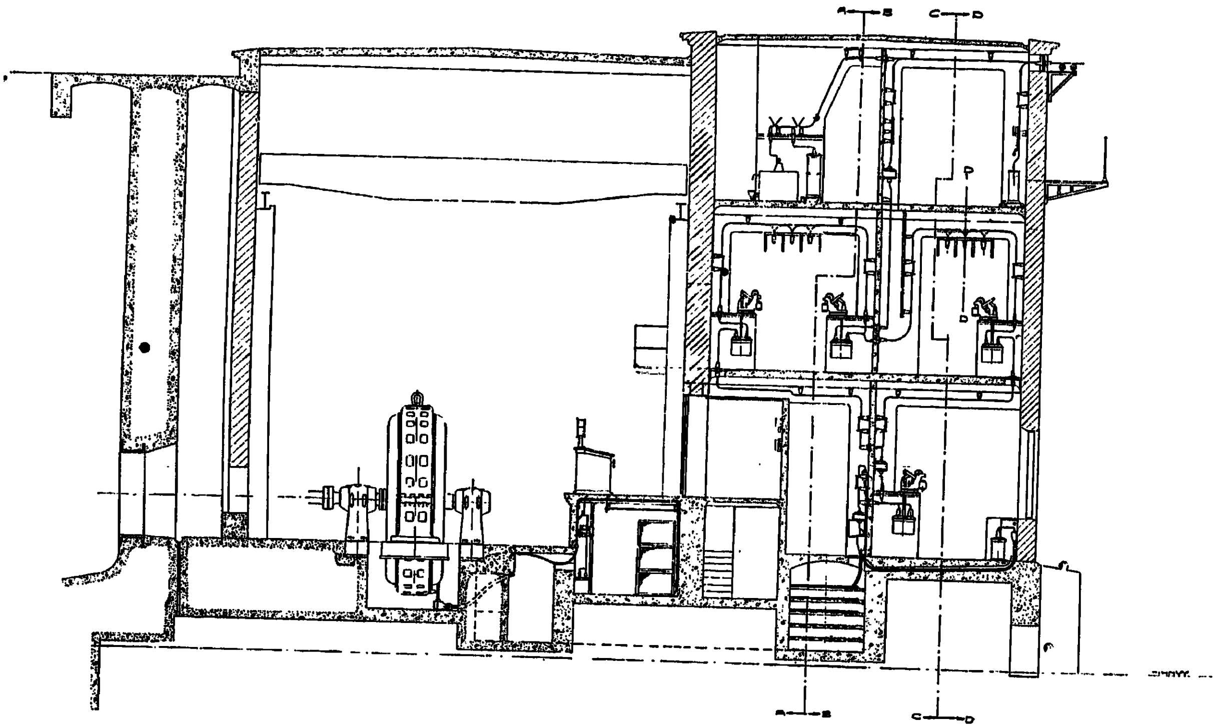


Fig. 125. Section of power station.

3 three-phase generators having a total capacity of 7800 KVA, exciter equipment of sufficient capacity to deal with the whole station when eventually completed, and all necessary switchgear. This order was executed during the first half of 1911 and two years later Asea received a further order for two more generators identical with those originally supplied, for extensions to the station. The demand for power steadily rose, so that after two years the station was fully loaded and Asea received a further order for two more generators similar to the previous ones. These machines were delivered in 1916, bringing the total capacity of the power-house up to the estimated 21000 water horse power available and for which the station had been laid out in the first instance.

The demand for power continued to increase at such a rate that in the following year the company was forced to commence developing their water power at Krakerud — a water fall a little further up the river. Asea received the order for the electrical equipment of this station and the generators fore same will soon be ready for delivery — the total capacity of this new plant will be 12500 HP.

Fig 126. Tännforsen in Jämtland.

Fig 127. Switchboard at Forshultsforsen power station.

The seven three-phase generators at Forshultsforsen power station are designed for a continuous load of 2600 KVA, 12000 volts, 187.5 r. p. m. Investigations showed that the most economical way to transmit the power over the 15 km line was by using the highest generator voltage possible and connecting direct to the electric furnace transformers without stepping up. It might be suggested that by stepping up, a more advantageous generator winding could be used and a voltage suitable for transmission selected, but it was found that double step-down transformers would have to be used to get down to a suitable voltage for the furnaces. On these grounds, Asea suggested using the generator voltage for transmission, and the machines were accordingly designed for the highest permissible voltage consistent with thorough reliability. For this reason 12000 volts was selected and since the installation has been in service it has proved beyond doubt that this was the most satisfactory way of dealing with the situation. During the whole time it has been running (which in 1916 totalled 100000 generator hours) the system has worked perfectly with one minor exception, when one of the generators developed a partial short. It must be emphasized that these generators work direct on the

Fig. 128. View of Porjus Falls.

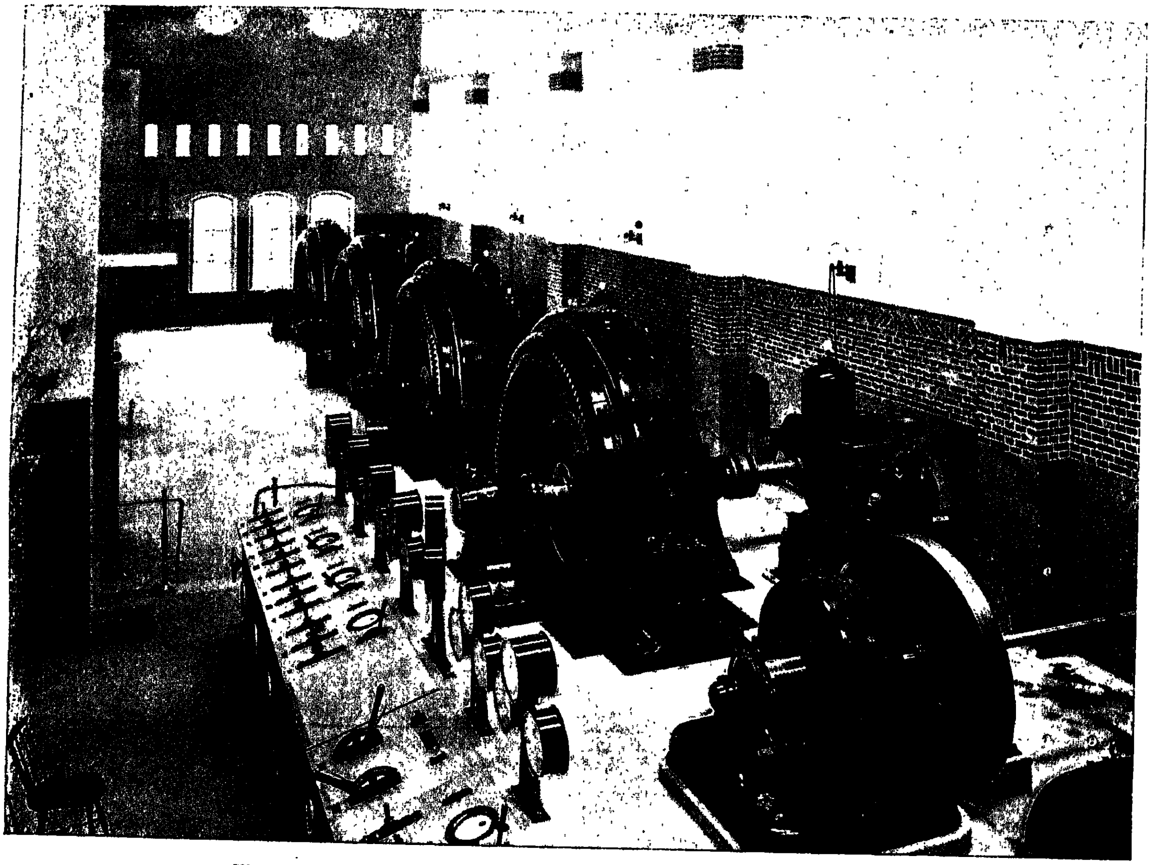


Fig. 129. View of generator room taken from the switchboard gallery.

overhead transmission line, which after all is regarded — and rightly so — as an undesirable practice, but the special nature of the transmission and the purpose for which the power is supplied, fully warrants the procedure. One of the generators, designed for 12000 volts, has for one year been used to feed an overhead 14500 volts transmission line without the slightest trouble.

The generators are open type, stationary armature, rotating field carried on horizontal shafts, fitted with solid flanges for coupling to turbines. The stator frames are of cast iron provided with openings as exits for warm air. To ensure good ventilation and prevent unpleasant air circulation in the generator room, the machines are furnished with cooling air brought from outside through ducts under the floor connected to the generator pits. On account of the low frequency the stators have comparatively thick laminations, built on standard lines with the laminations divided into sections for cooling, and secured in the frames

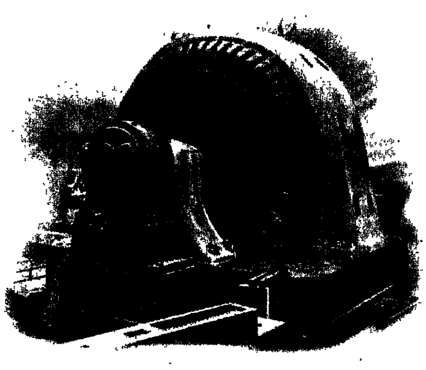


Fig. 130. 1000 KVA steam turbine driven three-phase generator at Skoghall.

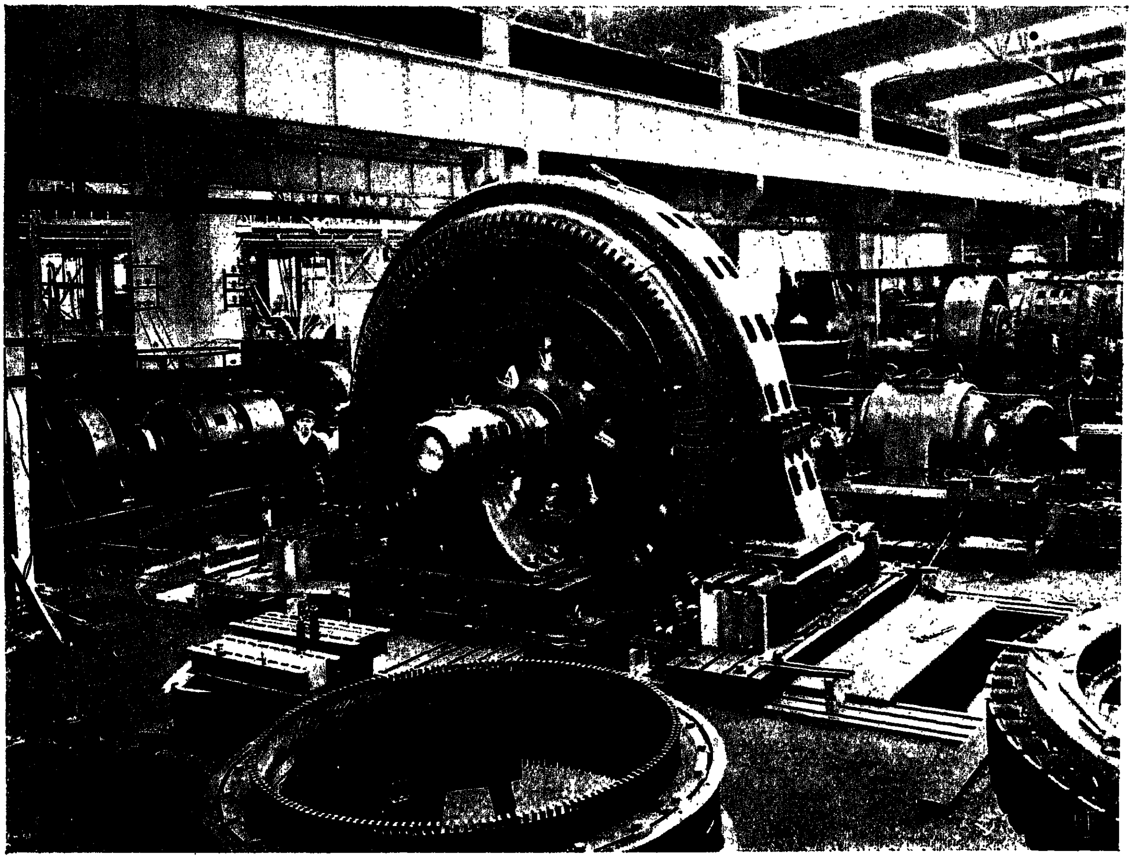


Fig. 181. Forshultsfors generator during test.

in the usual manner. There are 192 semi-closed slots in which the two plane winding is placed, the windings are insulated with seamless micanite tubes in the slots, and outside the laminations with empire cloth, etc. To prevent distortion on short-circuits and heavy surges, the coils are adequately supported and braced at the ends. The free ends of the coils are protected from mechanical injury by solid cast iron end chields as usually adopted on this type of machine.

The rotors are composite of steel and cast iron. In order to obtain the necessary flywheel effect for turbine regulation, a cast iron flywheel with an outer cast steel ring was used. The kinetic energy of the rotating masses is thereby brought up to 800000 kgms. The outer ring is cast in one piece with the poles and shrunk on the cast iron ring, which is also in one piece with the arms and hub. The field winding is of copper strip wound on edge and insulated in the usual manner. The coils are held in place by the poleshoes bolted to the polepieces. The field winding is connected

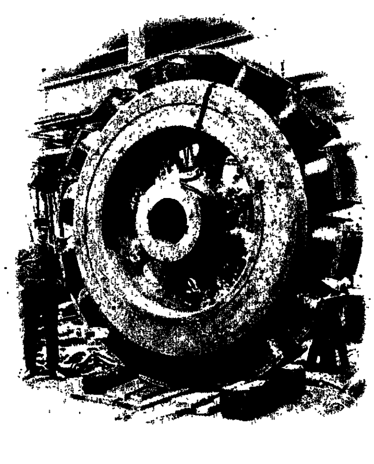


Fig. 182. Rotor for Forshultsfors generator.

to the collector rings (located between the rotor and one of the bearings), by the usual arrangement of leads brought down and secured to the shaft.

The length of the machines from turbine flange to outside bearing is 3.83 metres, the largest overall dimensions of stator across feet is 5.65 metres, and from floor level to highest point on stator 3.3 metres; the centre line of the machines is 1 metre above floor level and the generator pits are 1.6 metres below floor level. The weight of each machine is 63.3 tons; of this the stator weighs 24.5 tons rotor and shaft 33 tons, and the balance in bedplate, bearings, etc.

The power generated at Krakerud Station is supplied by three generators of which two are designed for a continuous output of 4300 KVA, 12000 volts, 150 r. p. m., 25 cycles; the third is somewhat smaller, 2100 KVA, 12000 volts, 187 r. p. m., 25 cycles. Each machine has its own direct connected exciter. All the machines are of Asea's standard open G type with stationary armatures, rotating fields, horizontal shafts with solid flanges for coupling to turbines. The shafts are bored out their full length for test purposes and to verify the soundness of the material. Generally the generators are of the same construction as those supplied to the Forshultsforsen Station. The dimensions are not however identical, as the output and speed are not the same. The smaller machine is 4 metres long from turbine flange to outside of exciter, 4.75 metres across stator feet, and from floor level to highest point on stator frame is 3.1 metres. The centre of the machine is 1 metre above the ground and the pit is 1.4 metres below floor level. The dimensions of the larger generators are: — length, 4.75 metres, across stator feet 7.23 metres, and vertically 4.1 metres, the centre line is 1 metre above and the pit 2.5 metres below floor level. The weight of the smaller machine is 41 tons, and the larger ones 71 tons each.

The rotors of these generators have extra heavy flywheels, those on the bigger machines having a kinetic energy of 970000 kgms and the smaller 375000 kgms. To obtain the large flywheel effect on the smaller generator without excessive weight, the rotor was made of a standard pattern with rim and poles in one piece of cast steel. To this was added two cast iron side rings of same internal diameter as the pole ring but carried up on the outside to partially overlap the field coils. These rings are somewhat narrow, and to ensure adequate ventilation they are placed a short distance from the pole ring, thus allowing the air to pass between to the field coils. In addition to the generators Asea also supplied all the other electrical equipment required for this power station.

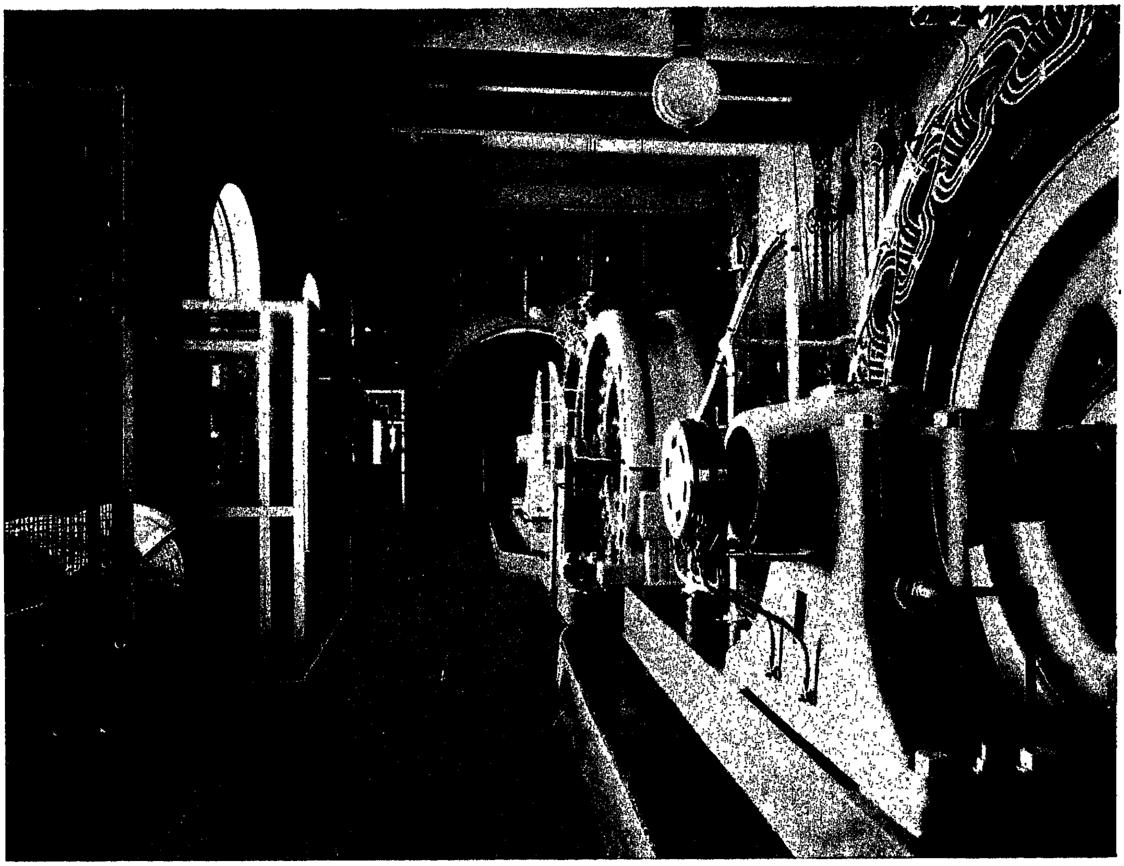


Fig. 133. Brattfors power station.

ÖREBRO POWER COMPANY

IN 1903 Asea delivered to the above company's water power station at Brattfors on the River Svartån (situated about 45 kms from Örebro) one three-phase generator for 2000 KVA, 20000 volts, 214 r. p. m., 50 cycles, and three years later a further generator for 2000 KVA, but running at 250 r. p. m.

When Asea received the order in 1902 for the first generator, a three-phase machine with such a high voltage had not been built. Estimates for an installation in Italy with this voltage were then under consideration but did not materialise. Subsequently, however, generators of this voltage and even higher were built, but only a long time after the Brattfors generators had been completed. Asea was probably the first Company to build such

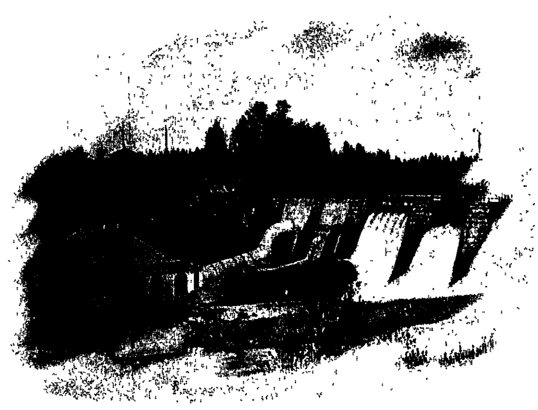


Fig. 134. Exterior view of power station.

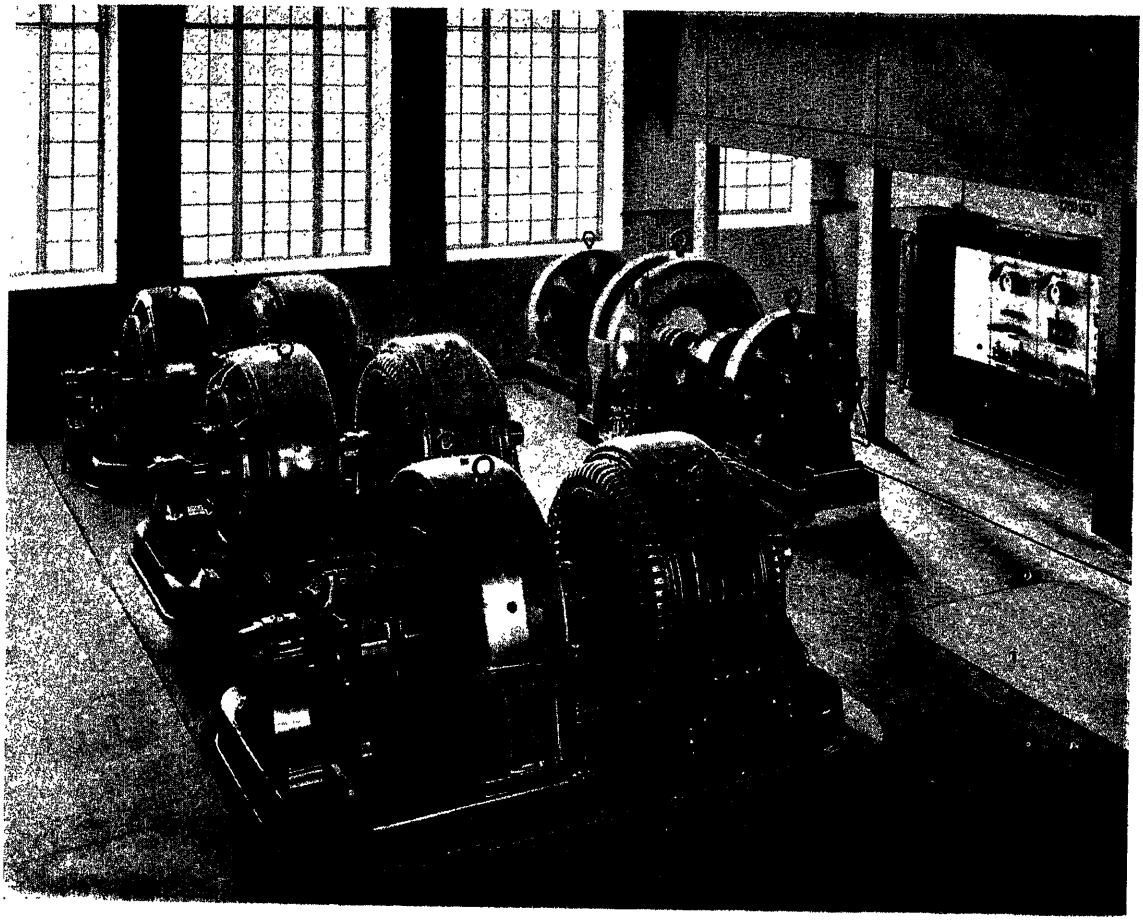


Fig. 135. Motor generator sub-station at Örebro.

high voltage generators. The first was a V-type machine rated for a continuous output of 1830 KVA, 15000—20000 volts, 214 r. p. m., 50 cycles so arranged that it could be connected for either 7500 or 10000 volts. Owing to the exceedingly low figures obtained on the temperature tests, both this machine and the one supplied later could be run with a continuous load of 2000 KVA. Although tested and run at 20000 volts the older generator is now used at 10000 volts as it supplies energy for an electric furnace, in which case only 10000 volts primary is needed.

Fig. 136. "White coal".

The generator has a stationary armature, rotating field, and horizontal shaft with solid flange for direct coupling to a water turbine. The stator frame is of cast iron split horizontally and, like the older types of Asea generators, has no

ventilating openings in the periphery: suitable openings of rectangular shape are however provided at the sides of frame. The upper and lower halves are securely bolted together and the latter has one detachable foot to permit the stator being turned on the rotor for special inspection or repairs.

The armature laminations are held in the frame in the usual manner and provided with ventilating ducts about 15 mm wide. The thickness of the laminations is unusual, being 0.7 mm. To take the winding there are 252 semi-closed slots. The coils are arranged in two planes with twelve conductors per slot, each insulated with double cotton covering and mica between layers. The conductors are insulated from the iron with micanite tubes, 6.5—7 mm thick. These extend about 150 mm beyond the iron and the projecting parts of the coils are insulated with mica and empire cloth to the same thickness as the micanite tube. The machine was tested with 25000 volts between copper and iron for one hour and run for ten minutes with 50 % above full voltage. The poles and poleshoes are of wrought iron, held together and secured to the magnet wheel with bolts. The ring is of cast iron reinforced with cast steel and is cast in one piece with the arms and hub. The field winding is copper strip on edge in one layer insulated between turns with paper and shellac, and from the iron with sterling paper and fibre. The collector rings are placed between the rotor and bearing and connected with the field coils by vulcanised cable. The kinetic energy of the roating masses is about 700000 kgms.

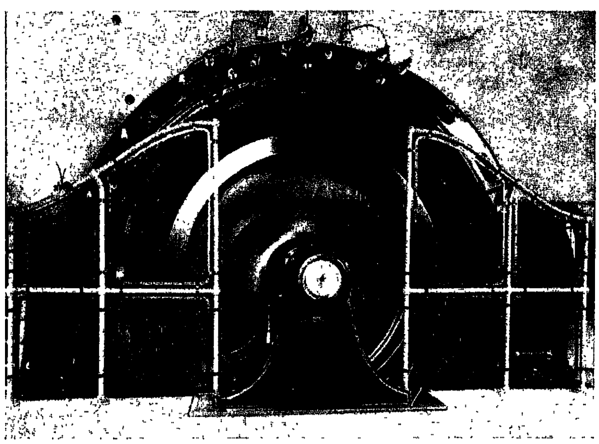


Fig. 187. 2000 KVA, 20000 volts, three-phase generator at Brattfors.

The length of the machine is 3.3 metres from the coupling flange to outside of bearing, 4 metres across the feet; highest point of stator frame is 3.1 metres above floor level and centre line of machine 1 metre above floor. The weight of the whole machine is 42 tons, of which 19 tons is in the stator, 18.5 tons in rotor and shaft, the rest in bedplate and bearings.

As previously mentioned, Asea received a further order three years later for another generator of the same capacity, *i. e.* 2000 KVA, 15000—20000 volts at 250 r. p. m., 50 cycles. The generator is of the same design as the other with only such changes as were inevitable on account of the higher speed. The stator is somewhat smaller in diameter and

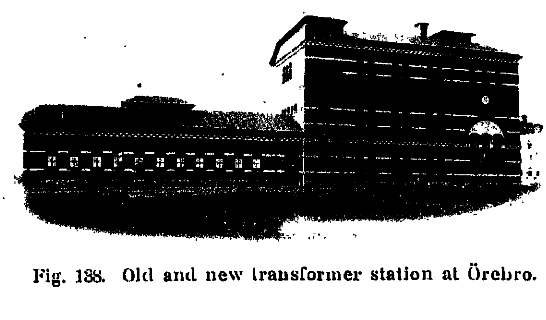


Fig. 188. Old and new transformer station at Örebro.

length, but in all other details the same as the original generator and stator, being furnished with one removable foot to enable the stator to be turned round on the rotor for repairs to be carried out on the lower half if necessary. The stator laminations are 0.5 mm sheet iron, there are 216 semi-closed slots to take the coils, which are arranged in two planes. These are more heavily insulated than the older machine and were tested between copper and iron with 30000 volts for one hour and run for 15 min. with 50 % above normal voltage.

The rotor is somewhat different from the older machines; in this machine the polepieces and ring are in one casting made of Siemens Martin Steel. Inside the steel ring is a cast iron ring to obtain the requisite flywheel effect for the turbine regulation. This ring is cast in one piece with the arms and hub of the rotor and the steel ring is shrunk on to it. The field winding is perfectly standard, that is, one layer of copper strip on edge. The shaft differs from those of the former machines, in that it is bored sufficiently far to take the leads between the field winding and the collector rings placed outside the bearings.

The kinetic energy of the rotating masses is 615000 kgms.

The overall length of machine is 3.83 metres from turbine flange to the outside of collector rings; across stator feet 5.36 metres and from floor level to highest point on stator 2.93 metres, depth of generator pit 1.65 metres.

The weight of the complete machine is 38.5 tons of which 16.5 tons is in stator, 14.8 tons in rotor and shaft, and the remainder in bedplate and bearings.

This machine was subjected to a very careful test and all guarantees were so easily fulfilled that the inspecting engineer concluded his report with the following remarks: —

"My opinion of the whole equipment and especially the three-phase generator is so good that I consider it, not only in workmanship but also in design, one of the best equipments ever built."

That this is no exaggeration is proved by the fact that this machine after thirteen ars continuous work has not been changed in any way, nor has it been necessary make any repairs.

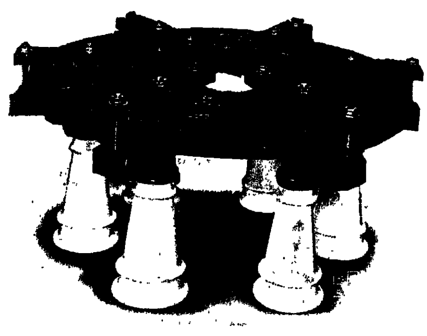


Fig. 139. Reactance coil for 4000 volts, 60 amps.

FOREIGN INSTALLATIONS

Fig. 140. Rjukan 1916. Westfjord showing nitrate plants and Saaheim.

NORSK HYDRO ELEKTRISK KVAELSTOF A/S.

(THE HYDRO-ELECTRIC NITROGEN COMPANY OF NORWAY)

THIS company — whose name is known all over the world — requires a considerable amount of electrical energy for the production of its various nitrogen combinations. The nitrogen is abstracted from the air by the Birkeland Eydes process and to supply the necessary electrical energy, subsidiary companies were formed for the purpose of building and equipping power plants. These companies are the Rjukanfos and Svaelgfos companies, who erected five large hydro-electric power stations in Telemarken, Norway, and for which plants Asea supplied the majority of the generators and other electrical equipment.

Some of the older and smaller plants are located at Notodden and are supplied with

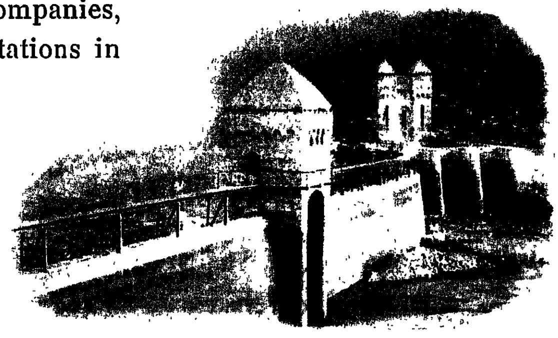


Fig. 141. Dam at Skarfos.

Fig. 142. Lower part of Westfjord and Saaheim

power from the Svaelgfos power company's stations at Svaelgfos, Svaelgfos' auxiliary station and Lienfos. The two first mentioned with a combined output of 60000 HP, have been equipped by Asea and the latter of about 20000 HP capacity by another firm. The other larger and more modern works are located at Saaheim and are supplied with power from the Rjukanfos company's power station at Vemork or Rjukan I and Saaheim or Rjukan II. These average 160000 HP each, and of the total no less than 170000 HP is produced by Asea generators.

These power stations utilize the water power of the river Skienelven (the third largest river in Norway), and also from one of its tributaries (Manelvend) whose source is the Hardanger plateau watersheds. This is a high lying part of the country from which the Skienelven also derives part of its water. For shipping and industries in the lower part of the river Skienelven, river improvements were put in hand in the latter part of the nineteenth century, and now take in the tributaries for this river, but the first of these, the dams at Mösvand were not ready until 1908. This dam is 180 metres long and 25 metres high; by it, the water depth in the small Mösvand lake through which the Maanelven flows is raised to 12 metres; at the same time the outflow of this lake has been dredged and lowered 2.5 metres so that the total head of water available is 14.5 metres. This reservoir has a capacity of 768 million cubic metres and allows a constant flow of water in the Maanelven from 45 to 52 metres per sec. throughout the whole year. The top of the Mösvand dam is 914.5 metres above sea level. This dam, served its original purpose of regulating the water for one of the branches (Tinnelven) of the main river, and for the power station and ship canals lower down,

Fig. 143. Dam at Mösvand.

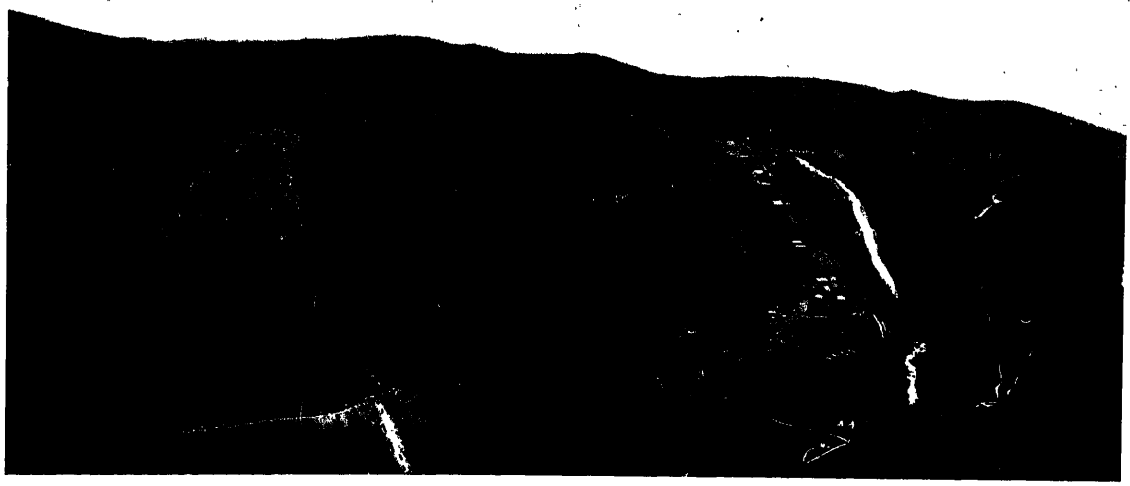


Fig. 144. Upper part of Westfjord and Vemork.

for a few years only; it was then allowed to flow in the old river bed, but on the commencement of Rjukan power station certain changes were made. The Maanelven now runs in it's original bed for a distance of about 8 kms to what is known as the Skarfors lake which with its dam (120 metres wide and 14 metres high) conserves the water, thus forming a reservoir for the tunnel — 4 kms long — blasted from the solid rock. This tunnel has an area of 26 square metres and leads to the distributing reservoirs — also blasted from the solid rock — above Vemorks power station. The top of the Skarfos dam is 855.5 metres above sea level and the distribution reservoir is 9 metres lower. From the distribution reservoir the water passes through several head gates to 11 flumes which start with a diameter of two metres, and of which ten taper down to 1.25 metres and the other to 1.6 metres at the power station situated 280 metres below. All the water mains are carried down in the open supported on concrete bases with solid foundations. Each of the turbines is supplied with water from a separate flume and is designed for a continuous load of 14500 HP. Another turbine of 1000 HP in the same power house is used to drive a generator which acts as a spare exciter and supplies light and power for the station.

The eleventh flume was put in to supply water for two 14500 HP turbines which are to be erected in an extension to the power house; of these sets only one is at present installed. The water from this flume can also be passed through a tunnel to the Saaheim plant. Before this plant was started in 1915 the water was returned to the Maanelven river.

The tunnel from Vemork to Saaheim with a length of 5.66 kms and an area of 32 sq. metres is blasted through solid rock commencing at the Vemork

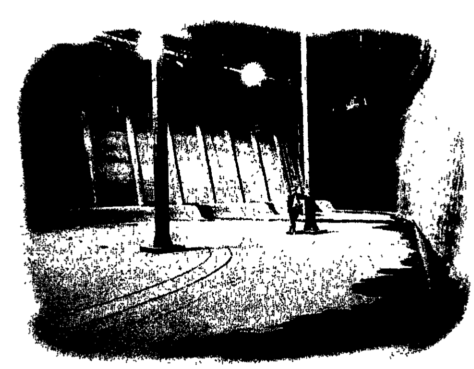


Fig. 145 Forebay above Vemork power station.

Fig. 146. Saaheim works.

station, and the water from the turbines is discharged direct into this. Should the station at Vemork be shut down for any reason the water can be byepassed from the distribution reservoir through a tunnel running parallel with the flumes, and by this means diverted to the tunnel which connects Vemork and Saaheim, making the latter independent of the running of the former.

The Saaheim tunnel discharges into a receiving reservoir consisting of three lakes blasted out of the mountain, from which three groups of flumes take the water down to the Saaheim station. The water can be taken past the station and discharged into the river through a special discharge tunnel, so that the flumes can be shut off regardless of water coming down through the feeder canal. The flumes are arranged in three groups in a tunnel blasted in the mountain side, each group consisting of three flumes. Of these seven start with a diameter of 1.6 metres and taper down to 1.3 metres, the remaining two are somewhat bigger starting with 1.79 metres tapering down to 1.43 metres.

Fig. 147. 8750 KW furnaces at Saaheim works.

This pipe line, as well as the turbines at Vemork,

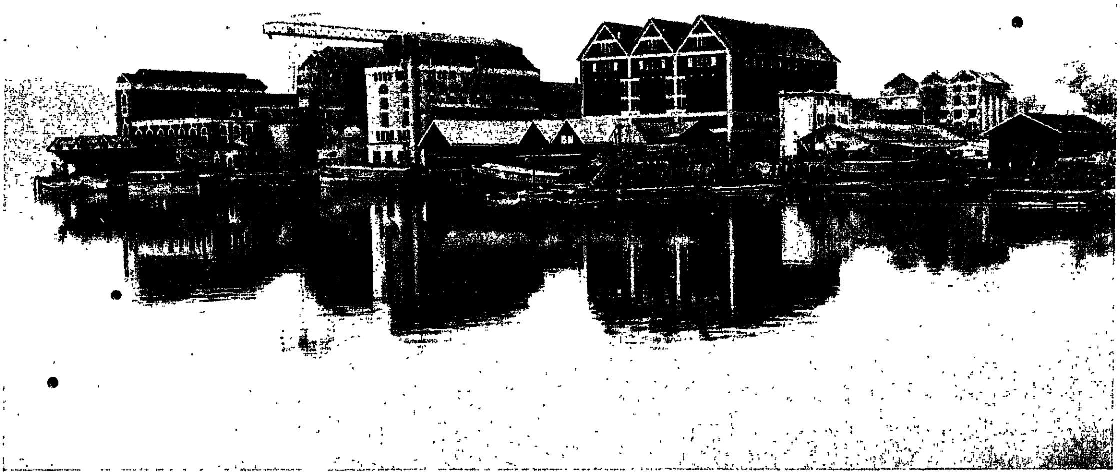


Fig. 148. Nitrate works at Notodden.

are fitted with automatic valves close to the distribution reservoir, which close should the velocity of the water exceed that for which the automatic valves are set. If necessary they can also be operated by hand or by an electrical device from the switchboard.

In Saaheim, where the useful head is 250 metres, there are nine 16400 HP turbines and one 1000 HP turbine. They are of the same design as the turbines at Vemork, with the exception of their greater capacity. Above the station there are branches in two of the pipe lines connecting with a reservoir which furnishes the water required to run the industrial plant at Saaheim. Before the water discharges into the reservoir it drives a 7000 HP turbine similar to the one erected in the power house, direct coupled to a three-phase generator which is run in parallel with a the generator of the same size in the power house and which has its output regulated by the amount of water used at the factory. When this is diminished the water for this turbine is also diminished and thus the load is automatically taken up by the generator in the power house. These two generators in parallel furnish power for the auxiliary machinery in the saltpetre plant, consisting of pumps, fans, cranes, etc.

Fig. 149. A furnace room in Notodden with 800 KW furnaces.

Some of the large turbines in the power station are of the Pelton type with two wheels on one shaft and have two steel nozzles for each wheel; they are each direct coupled to one three-phase generator described below and run at 250 r. p. m.

From the two power stations the power is transmitted by overhead lines, one line for each generator, at 11000 volts from the most distant station at Vemork and at 9500 volts from the Saaheim station to the saltpetre works at Saaheim, where all the power about 230000 KW is utilised for producing nitric acid on the Birkeland-Eyde's system by oxidising the nitrogen in the air by big electric arcs of unusual shape. The greater part of the acid is used to produce the important fertilizer "Norgesalpeter" (Norwegian saltpetre) and the smaller part for the production of explosives and chemical products.

From the Saaheim power station the water is discharged into the river Maanelven, which a few kilometres lower down runs into the long narrow lake Tinnsjön; this acts as a reservoir for the power station at Svaelgfos and Svaelgfos auxiliary station, etc., situated at the outflow of the lake.

The regulation of lake Tinnsjön is accomplished by means of a dam built near the outlet; this raises the water level by as much as 4 metres, at which height a supply of water equal to 204 million cubic metres is held in storage, so that the water flow in the river Tinnelven, with the help of the water from Mösvand, can be kept continually at 76 cubic metres per second the whole year round.

From the dam at Tinnsjön the water flows for about 20 kms down to a narrow pass called Svælgfosjuvet, where a dam about 30 metres high (Svælgfosdam) has been constructed. By means of this dam a reservoir has been formed which is 5 kms long, and is known as Svælgfossjön. From this lake the water is taken partly through an open canal and partly through a tunnel to the fore bay of Svælgfos station, whence it is taken through four flumes laid in the mountain side to the power station, and part of the water supply is also carried in two flumes on the surface of the mountain down to Svælgfos auxiliary station situated lower down the valley. In both stations a head of 48 metres is available. Each station is equipped with 10000 HP turbines direct coupled to three-phase generators of the same capacity, of which there are four units in the main power house and two in the auxiliary station.

From these two stations the power is transmitted on overhead lines in the same manner as the Rjukan system, to the salpetre works at Notodden about 5 kms south of Svælgfos and is utilised for the same purpose as at the Saaheim plant.

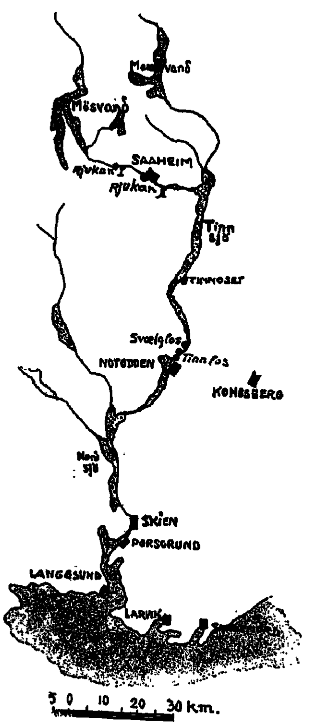


Fig. 150. Line Map showing part of the river Skien.

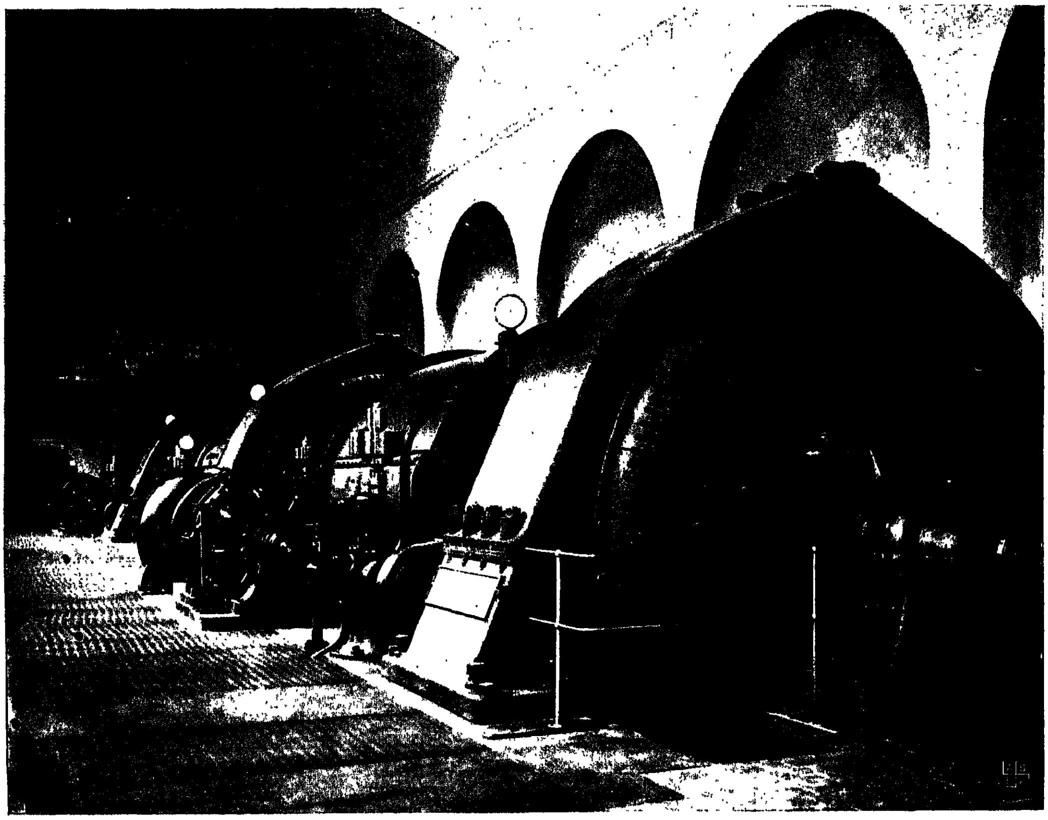


Fig. 151. Interior of Svælgfos Power station.

SVÆLGFOS POWER STATION

IN the spring of 1906 the preliminary work of building this station was commenced, and after the specifications had been drawn up and everything settled with regard to type and size of the machinery to be installed, Asea received an order at the end of July of the same year for four three-phase synchronous generators for which the plant was designed. Owing to the necessity of supplying power at the earliest possible moment to the saltpetre plant at Notodden, (which owing to its rapid development had to obtain a further supply of energy), the date of delivery was fixed for the 1st July of the following year, by which time the machines had to be erected and were to be ready to start regular operation. The contract was quite an undertaking when the means of transport and the erection facilities at Svælgfos are considered, as well as the fact that the machines

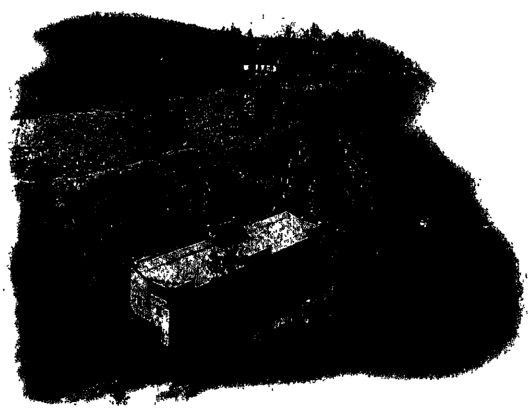


Fig. 152. Outside view of the station.

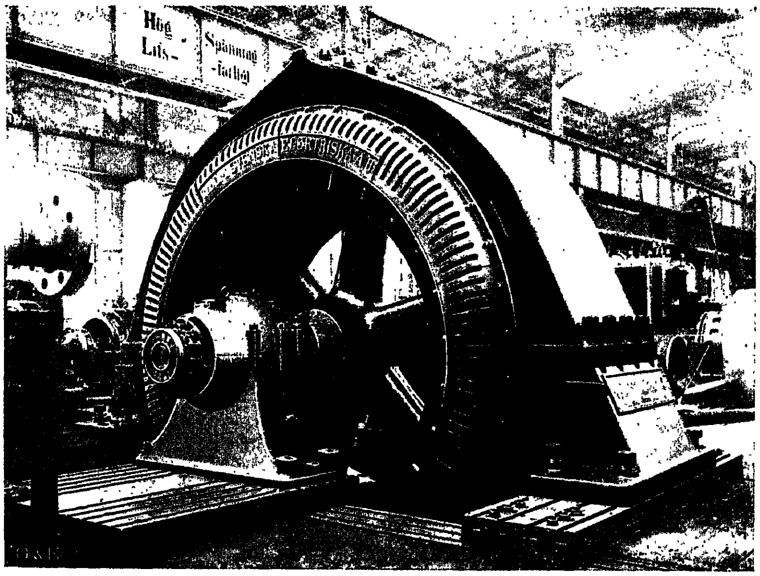


Fig. 153. 10500 KVA generator for Svælgfos in the Emaus Test Room.

were considerably larger than any built by Asea at that time, in fact they were then the biggest machines built in the world. Taking all these factors into consideration, the time of delivery was very short. The work was pushed through the shops and the date fixed for starting up could have been kept if delays in delivery of other parts, not supplied by Asea, had not held the erection back; thus after the plant had been delivered it could not be completely erected. Instead of the stipulated date for starting, the station was not ready to operate until the early part of October, although the first generator was on its foundation by the middle of May and all the rest of the equipment was in or at the power house at the same time. The station was then run without a stop until the beginning of the following year.

By this time sufficient information had been collected, thanks to the additional data supplied by the Svælgfos station, which commenced to furnish power for the manufacture of saltpetre, showing that only one voltage was needed, 10000 volts, so that the provision made to connect the generators for a lower voltage at the time of their design was not needed. As the re-connection of the generators had several disadvantages, especially from the unavoidable equalising currents generating heat and the consequent danger of damaging the insulation, the original windings were changed and ordinary 10000 volt windings placed in the machines. Since making this alteration they have worked steadily without giving any trouble.

The generators are direct connected to double wheel Francis type turbines erected in one line parallel with and close to one of the walls of the station. This unusual way of arranging the machines had to be adopted in order to make the building as narrow as possible, as it is built on a shelf blasted out of the mountain side. For the same reason the four machines are placed as close together as possible and the generator parts are not longer than is absolutely necessary for mounting the machines and allowing sufficient room for the necessary ventilating air ducts.

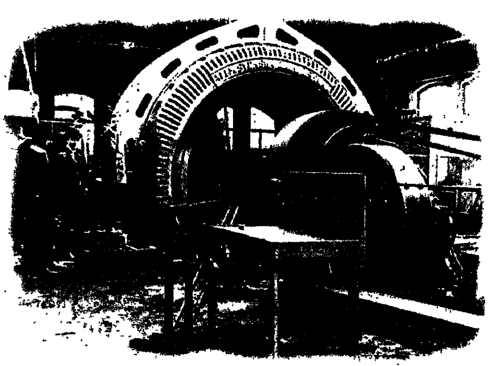


Fig. 154. Acceptance test of Svælgfos generator.

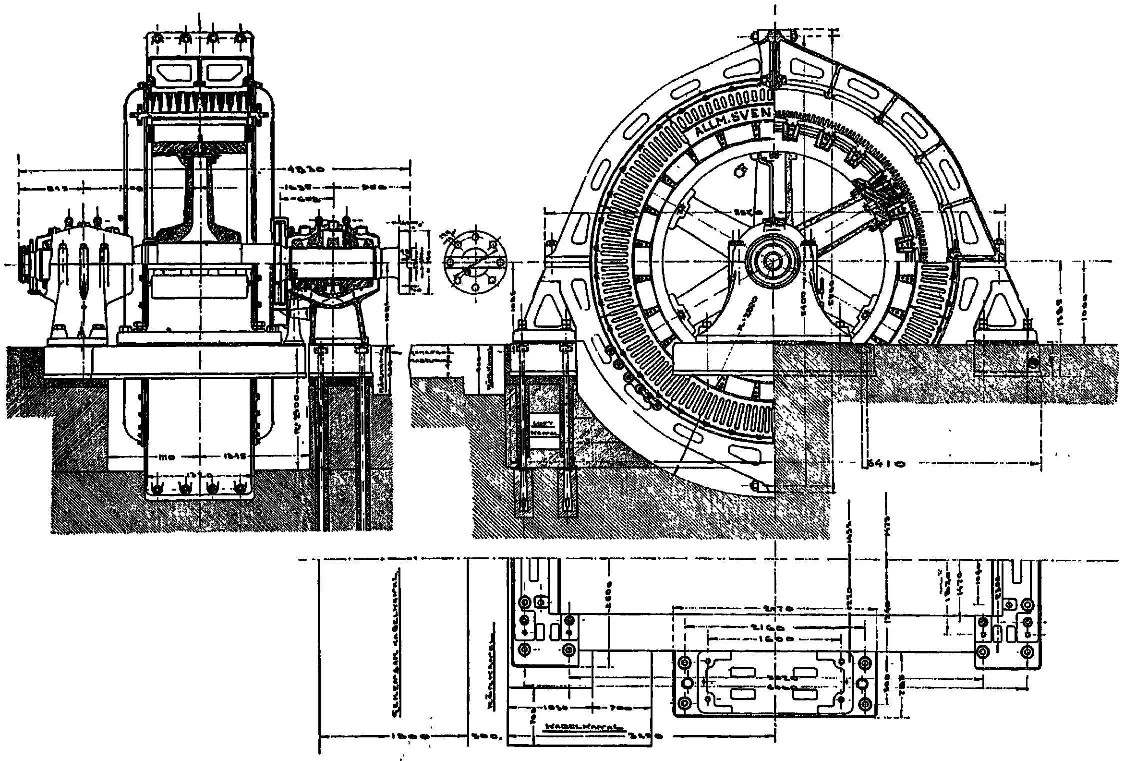


Fig. 155. 10500 KVA three-phase generator for Svælgfos.

The four generators are all similar, of the open type with stationary armatures, rotating fields on horizontal shafts with solid flanges for direct coupling to the turbines. The open type of machine was decided upon as at the time of their design no similar large machines had been built, nor had a plant of such a capacity been placed in one building, so that it was not realised what disadvantages this construction brought about in big installations. The standard construction for older and smaller power houses was followed so that the station from a modern point of view is rather windy and the noise from the machines unpleasant. This disadvantage can be overcome by totally enclosing the machines, but this suggestion has not yet been adopted.

The generators are each designed for a constant output of 10500 KVA, 10000 volts, 250 r. p. m., 50 cycles, at 67 % power factor. The cast iron stator is divided in four parts so as to get each piece light enough for railway transportation, the maximum load over this line being 12 tons; these four parts are rigidly bolted together. To facilitate repairs to the bottom part of the stator one of the feet is detachable so that the stator can be turned part way round the rotor. The stator is of standard construction without air openings on the periphery of the stator frame but has openings at the ends, as shown in Fig. 155, also cast iron end shields

Fig. 156. The outlook from Notodden.

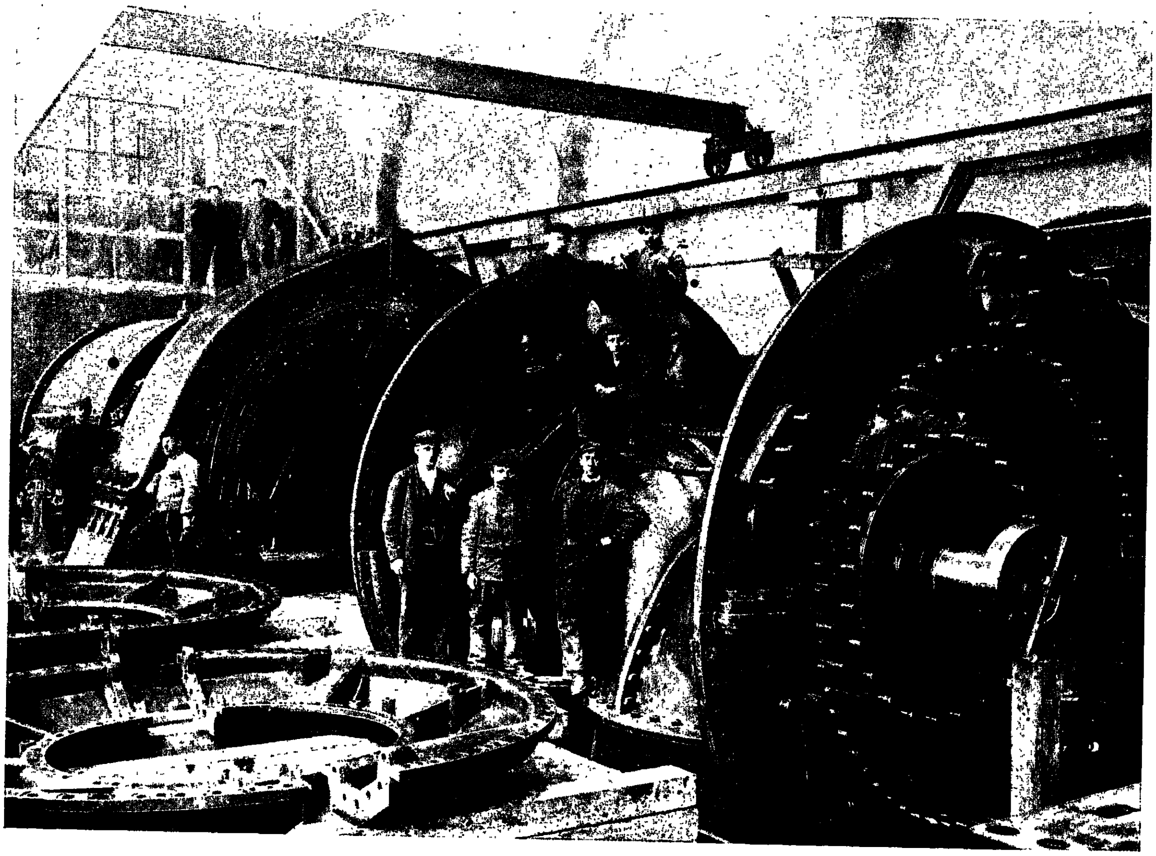


Fig. 157. Interior of the Power station showing machinery during erection.

over coil extensions. In the stator frame the laminations are of best Swedish sheet iron secured in the normal manner and have 216 open slots to take a three-plane winding. The winding has one straight coil and one bent outwards, and is unsupported outside the laminations. The coils are insulated from the frame by seamless micanite tubes held in the slots by means of wedges. The micanite insulation is divided into two parts, one enclosing each individual conductor and one which encloses all the conductors in one slot and insulates them from the iron. The inner micanite insulation is put on the conductors hot, with a special compound. The three conductors are then placed in one micanite tube which is applied under pressure and heat giving the tube the correct shape and uniting the inside insulation with the tube and forming a homogeneous mass. The individual conductors are insulated with impregnated double cotton. Outside the laminations the conductors are insulated separately with suitable tape in layers and then the whole taped together varnished and painted.

The rotor is made of Siemens Martin Steel with

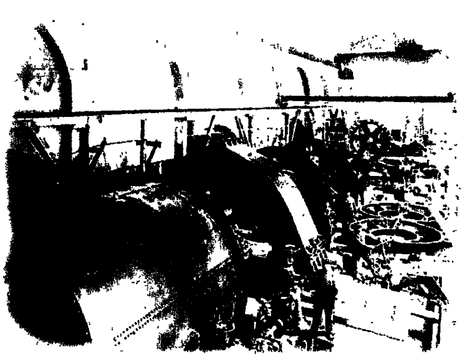


Fig. 158. Svælgfos Power station during erection.

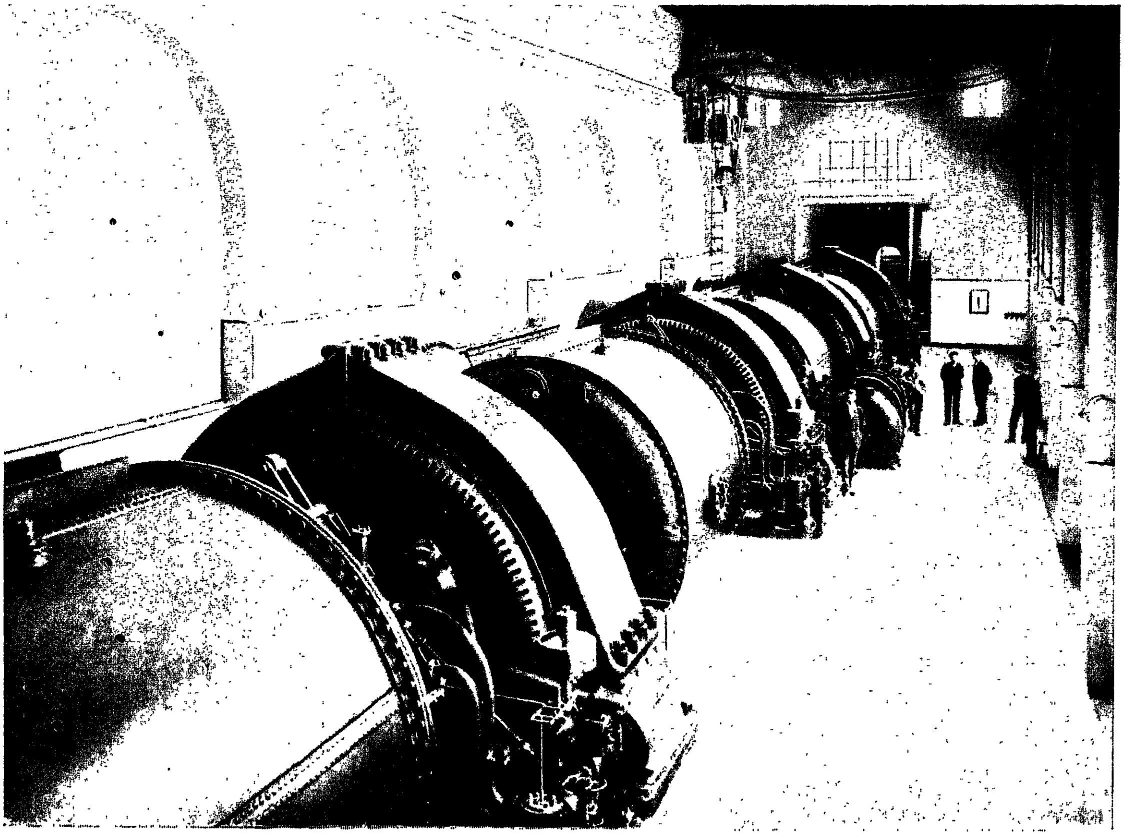


Fig. 159. Svælgfos station after the construction work was finished.

pole-pieces and ring in one piece, but the whole split in two parts, at right angles to the shaft and held together with bolts and distance pieces in such a manner that an opening is left between the two halves. The bolts that are used for holding these rings together are also used for securing them to the steel arms cast in one piece with the hub. The arms are made hollow to reduce the weight. The 24 poles are unusually long compared to the width; the ratio being no less than five times. The reason for this is that it was decided to keep the diameter of the rotors as small as possible so as to obtain a low peripheral speed, thereby reducing to a minimum the noise that air currents would produce in the open type generator.

For this reason and also to economise width in the power station the generators were designed with a small diameter but comparatively long axially. The radial ducts in the rotors do not go the whole way through the pole-pieces but stop a short distance from the end, so that the end of the pole-pieces as well as the pole-shoes are solid. The pole-shoes are laminated and securely bolted to the pole-pieces. The field

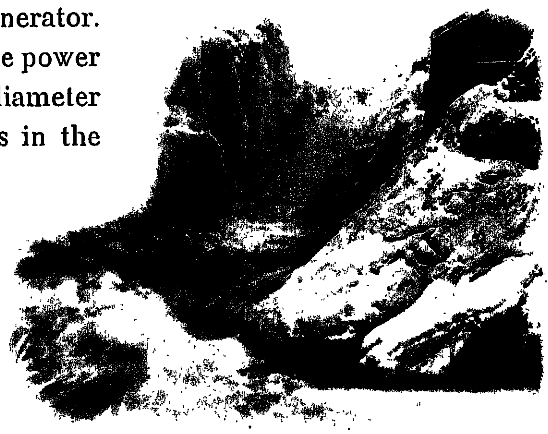


Fig. 160. In the grip of Winter.

coils are wound with single copper strip on edge and insulated between turns and from iron in the usual manner, *i. e.* with presspahn collars and washers the whole being held in place by the pole-shoes. Owing to the abnormal width of the poles there is a tendency for the field coils to pull away from the pole-pieces due to centrifugal forces; to prevent this, the coils are braced on each side by means of brackets fixed at the centre of the air duct. The collector rings are placed outside the bearings according to standard practice in older types of generators and are connected to the field coils by cables taken through the shaft which is counter bored.

The flywheel effect of the rotating masses is 2250000 kgms.

The rotor is carried on a forged shaft, made of the best Swedish charcoal steel, supported by two liberally designed bearings, one of which, namely the one next to the turbine, carries an additional load of 5 tons of the turbine weight. The bearings are designed for ring lubrication as well as pressure feed and water cooling.

The main dimensions of the generators are, 4.8 metres from turbine flange to outside of collector rings, 6.3 metres across the stator feet, 3.78 metres from floor level to highest point on stator, and the centre of machine is 1 metre above floor level. The generator pit is very narrow and has little clearance between the sides and the stator frame. The length of the pit is somewhat greater than necessary to take the generator, but is arranged in this way to secure an ample supply of cooling air.

The approximate weight of each machine is 104 tons, the stator weighing 51 tons, rotor and shaft 37 tons, the remainder being the weight of the bearings, bedplate, foundation bolts, etc.

Fig. 161. Power station during construction work.

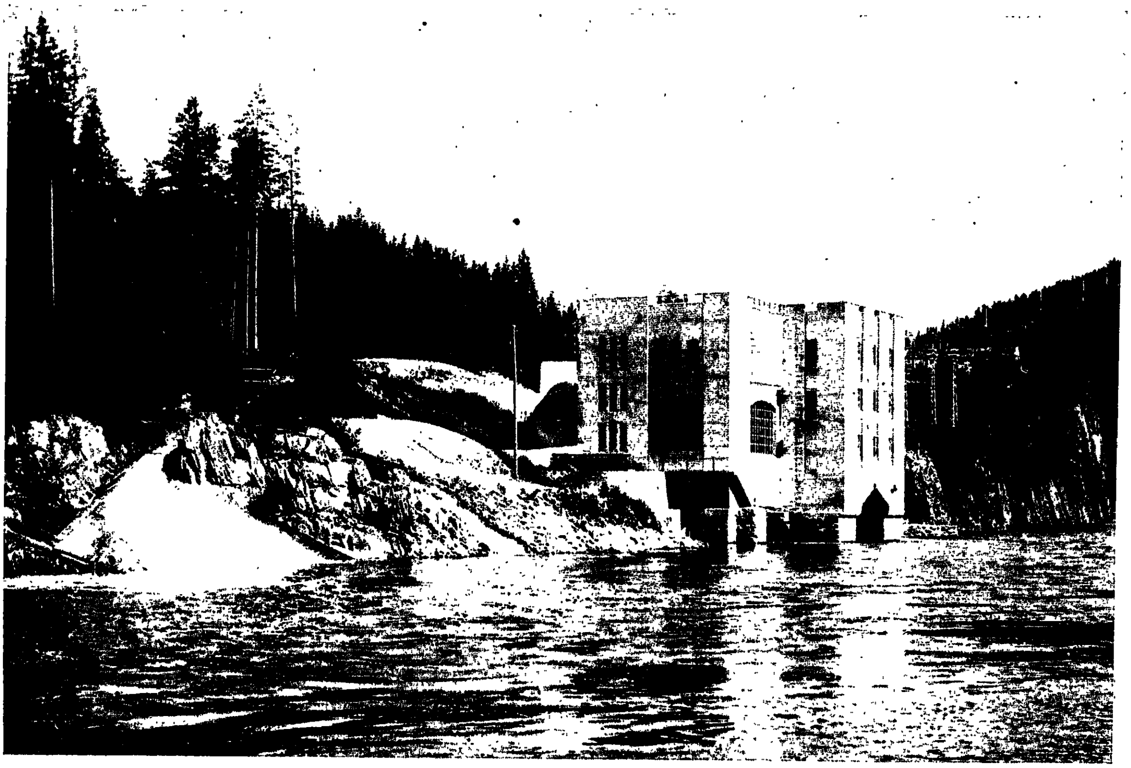


Fig. 162. Svælgfos Reserve station.

SVÆLGFOS RESERVE STATION.

AFTER the Svælgfos power station had been operating for about 4 years, the demand for power at Notodden had increased to such an extent that this station could not cope with it and means had to be found to increase the supply. Consequently, the A/S Svælgfos company decided to commence the construction of what is known as the Svælgfos reserve power house, which they had had under consideration for some time past. This plant is located about 600 metres below the Svælgfos station on the comparatively placid Tinnelven river, where the shores are far more favourable than at Svælgfos. In 1912 Asea received an order for the first equipment for this station, consisting of a three-phase generator, exciter and all necessary switchgear, the whole of which was delivered in the spring of 1913; this was followed in the autumn of the same year by a repeat order for another generator, exciter and switchgear, similar to the original plant and which was delivered in 1915.

Fig. 163. Svælgfos Dam.

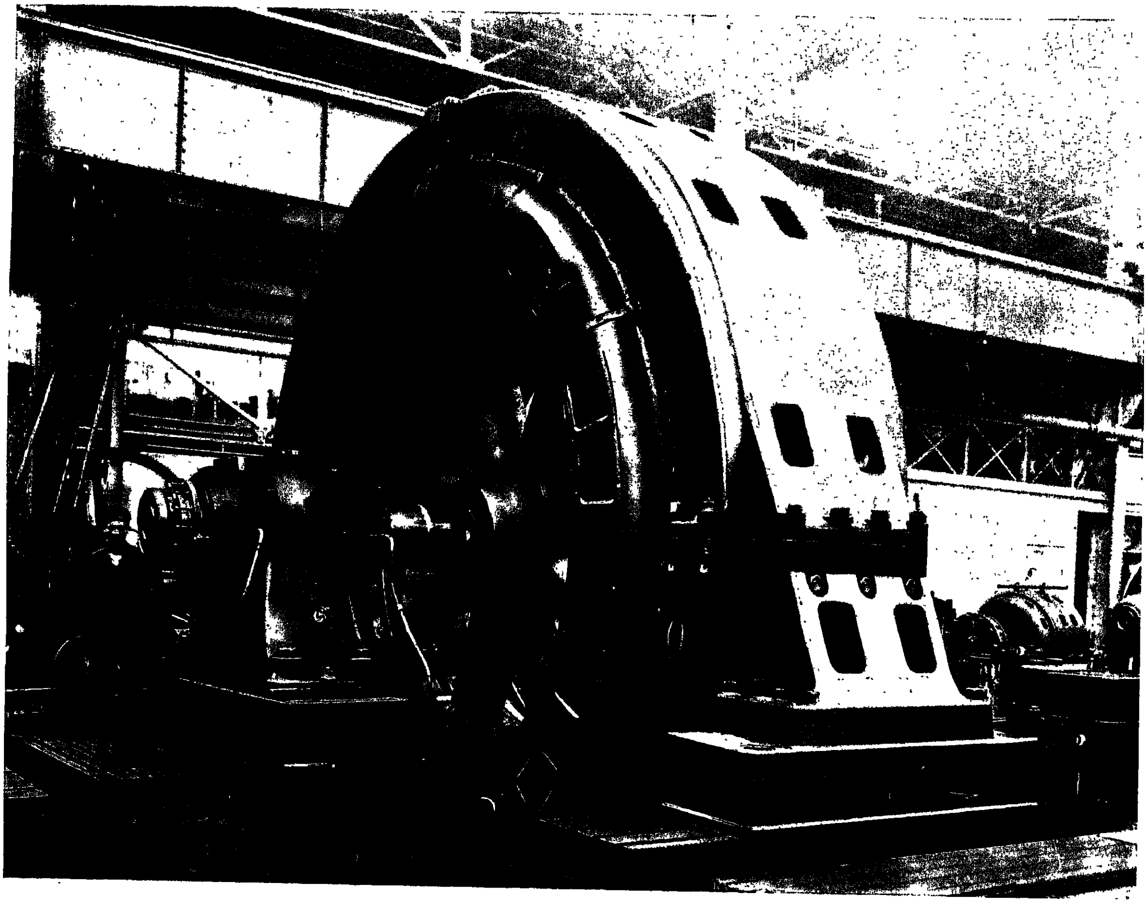


Fig. 164. The first generator for Svælgfos Reserve station erected for test.

Each generator is designed for a continuous output of 11000 KVA, 10000 volts, 250 r. p. m., 50 cycles at 67 % power factor. They are of the semi-enclosed type with stationary armatures, rotating fields on horizontal shafts with solid flanges for coupling to the turbines. After the experience gained at the older station, these units were designed as semi-enclosed machines in order to reduce the noise, consequently they run at a somewhat higher speed. The machines are so designed that they can be converted into totally enclosed machines, should it be desired on completion of the station, thereby reducing the windage noises to a minimum.

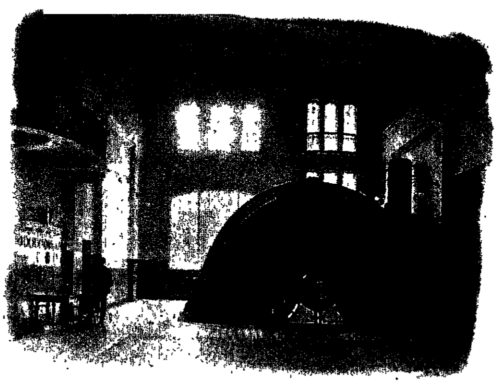


Fig. 165. Interior of the station — generator side.

The stator frames are made of cast iron and like the older machines are cast in four parts, this was done in order to be able to transport them over a cable-way having a maximum carrying capacity of 13.5 tons; the four sections are rigidly bolted together. As the generators were designed to be converted into totally enclosed machines at some future date, the stator frames have been

arranged as receiving chambers for warm air from the windings and are provided with outlets at the bottom where they connect with an air duct which carries the air to the warm air system. In the older station the machines are arranged with one detachable foot on the stator frame, so that the stators can be lowered on to the rotors and turned with them when repairs are necessary to the lower half. The same facilities for repairs to the stators were required at the new station, but owing to the solid end shields, these stators are much heavier, and in order to avoid any possibility of damaging the windings or laminations they are built with circular tracks resting on rollers in the bottom of the pits. By this means they can be rotated, after the detachable foot is removed, without coming into contact with the rotors.

The armature laminations are secured to the stator frame in the usual manner and have 216 open slots in which the winding is arranged in three planes. This type of winding, although undesirable in some respects, has the advantage that the machines can be taken apart without disturbing the windings in the slots. The conductors are insulated from iron and also between turns with 5 and 3.5 m/m. of micanite respectively. There are three conductors in each slot made up of several independently insulated bars, these are taped together, varnished and painted in the usual manner, where they project beyond the laminations.

The free ends of the coils are well braced by means of insulated brackets, to prevent distortion, due to stresses set up by short circuits or heavy surges on the line. To protect the windings from damage and to prevent accidental contact with the coils, the machines are fitted with end shields fastened to the stator frame extending inwards far enough to cover the pole ring. These end shields also serve to guide the cooling air and to deaden the noise made by air currents created by the rotors. Hinged inspection doors are arranged in the shields for cleaning purposes and examining the coils.

The rotor is made of Siemens Martin Steel with pole-pieces and ring in one casting; to facilitate transport and inspection of material they are divided into several discs, at right angles to the shaft. The pole-shoes are laminated and bolted to the pole-pieces, holding the field coils in position; the latter are of copper strip on edge insulated in the usual manner.

The rotors are provided with radial cooling ducts through the rotor ring and pole-pieces in order to effectively distribute the cooling air, thereby ensuring adequate ventilation to the centres of the rotors as well as stators. The field coils are provided with special cooling devices to give a greater cooling surface than is normally obtainable.

The rotor spiders and centres are of the same

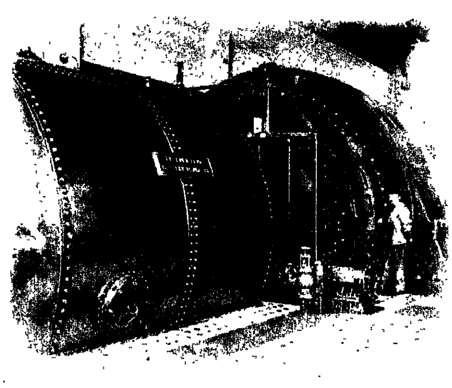


Fig. 166. Interior of the station — turbine side.

design as those in the older station, so also are the collector rings and arrangement for connecting same to the field. The shafts and bearings are of standard construction adopted for large machines.

The flywheel effect of the rotating masses is 4000000 kgms.

The principal dimensions of the machines are 5.44 metres from the turbine flange to the outside of the collector ring cover, 7.32 metres across the stator feet and 4.13 metres from floor level to highest point on stator. The pits are 2.6 metres below, and centre of machines 1 metre above floor level. Unlike the original station, the pits are made sufficiently large for a man to be able to work in them for cleaning or other purposes.

The weight of each complete generator is 125 tons, the stator weighing 65 tons, rotor and shaft 55 tons, bedplate, bearings, etc. making up the total. The field current is supplied by independent water turbine driven exciter sets.

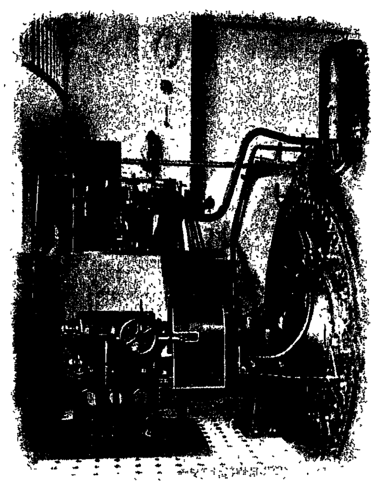


Fig. 167. Turbine governor.

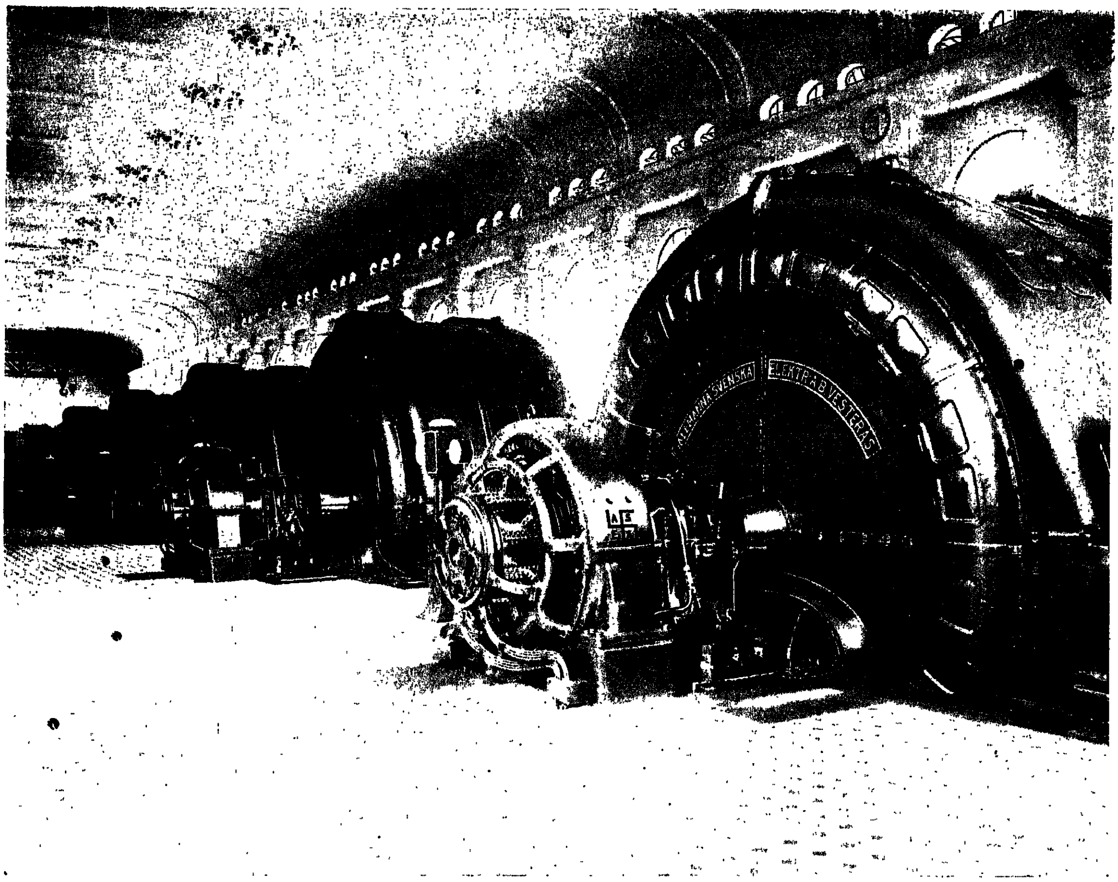


Fig. 168. Interior of Vemork Power station.

VEMORK POWER STATION.

DURING 1900 and the following few years, the Norsk Hydroelektrisk Kvaelstof Co. had purchased all water rights on the river Maanelven. This step was taken after their nitrate works at Notodden had developed into a flourishing industry due to the starting of the Svælgfos station, and enough data had been collected concerning the available supply of power; they then decided that the time was ripe to start developing the hydro-electric possibilities of the Maanelven river. In the spring of 1909 Asea received an order for 5 three-phase generators for the first power station on which the Hydroelektrisk Kvælstof Co., — through its subsidiary company the A/S Rjukanfos — commenced construction work at Vemork situated on the above mentioned river in the upper part of the Vestfjord valley.

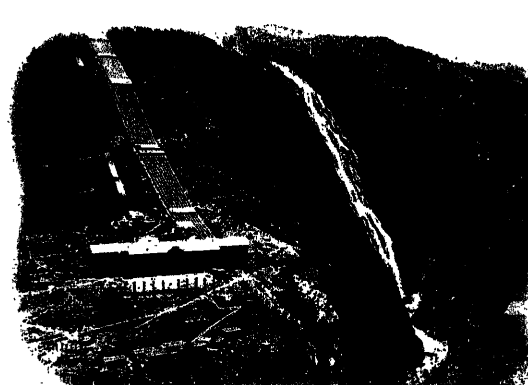


Fig. 169. Exterior view of the station.

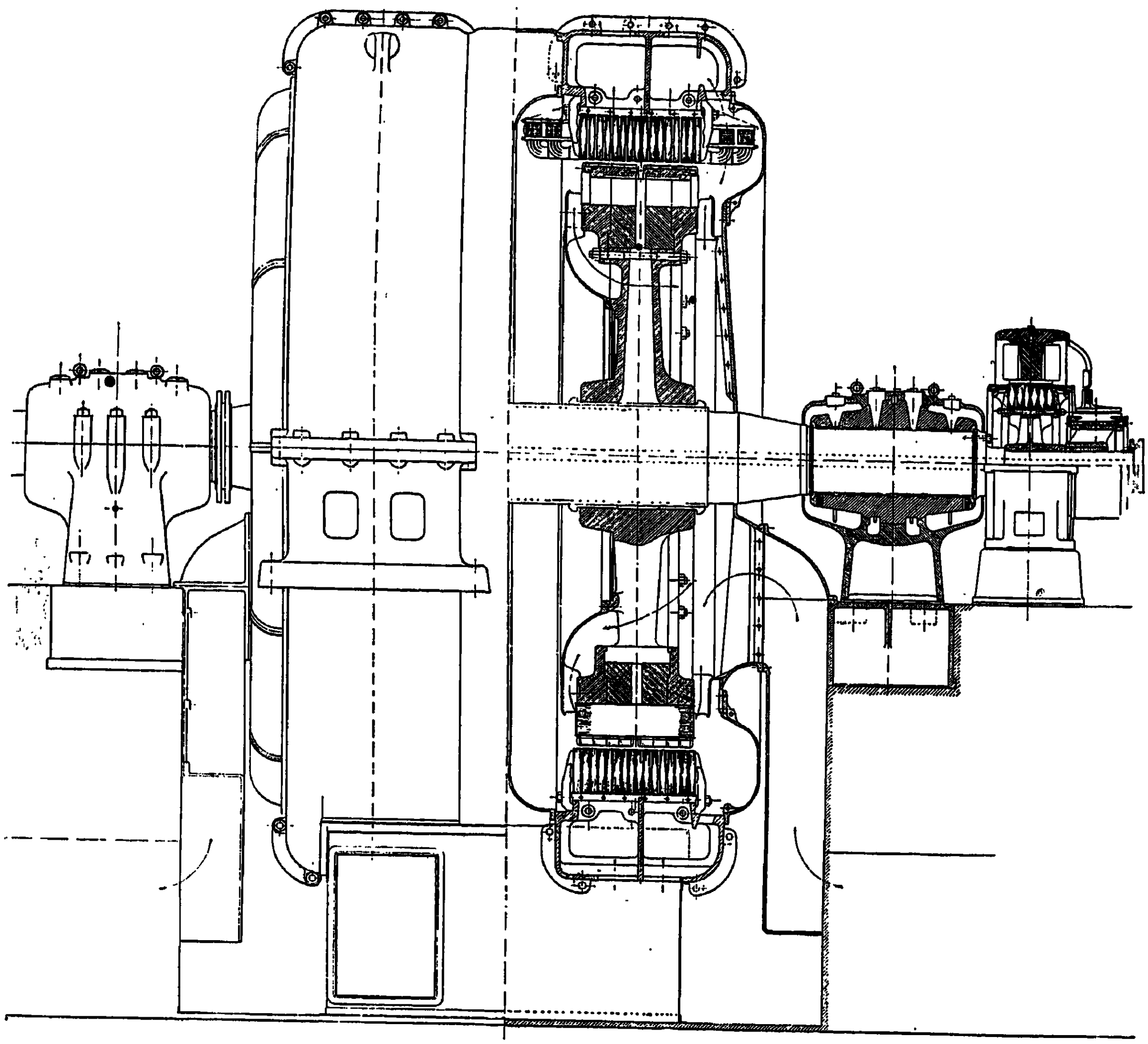


Fig. 170. 17000 KVA twin-generator for Rjukan I.

Based on the enormous amount of water power capable of development at this station, it was decided to make the units as large as possible. At Notodden it had not been advisable to design the machines for more than 10500 KVA. At the time the order was placed it had not been definitely decided how the connection between the furnaces was to be made nor how they should be connected up to the new generators, however instructions were issued to build the generators as two unit machines with two rotors on one shaft coupled to one turbine. The generators were constructed as two independent machines so far as the electrical design was concerned but with one shaft.

The twin-generators were therefore arranged

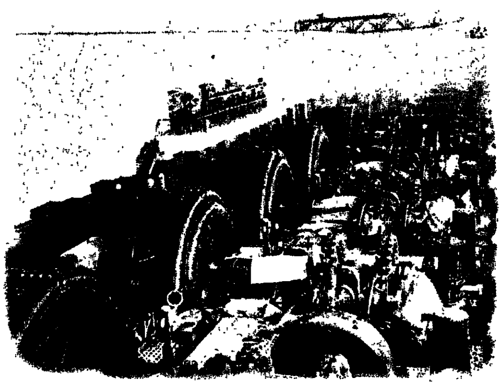


Fig. 171. Power station during construction.

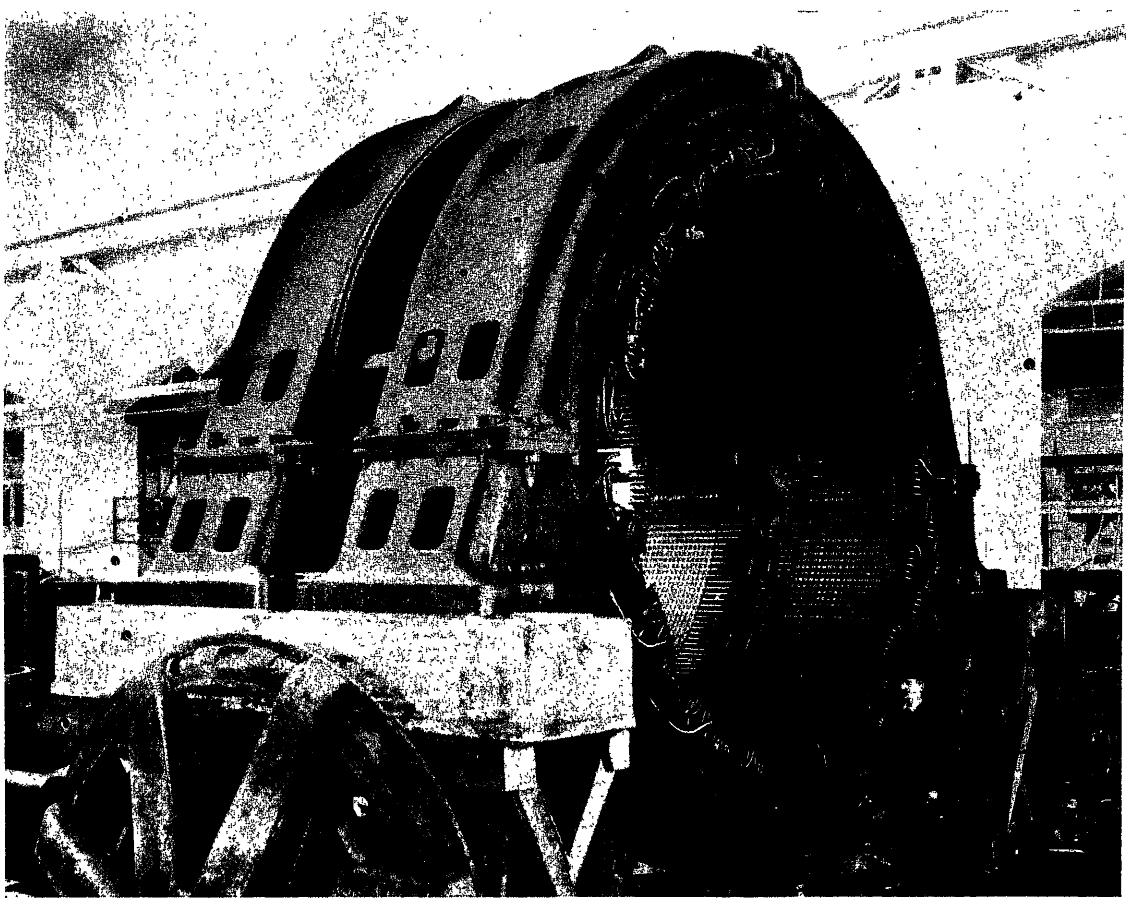


Fig. 172. Stators for twin-generator.

for a continuous turbine rating of 14450 HP representing 17000 KVA for the two generators, or 8500 KVA each at 10000—11000 volts, 250 r. p. m., 50 cycles and 60 % power factor. This load is carried day and night during the whole year, with the temperature rise of the generators guaranteed not to exceed 50° C. The generators were so liberally designed that the maximum output of the turbines *i. e.* 15700 HP, can be utilised. The two generators are designed for parallel operation with the other machines in the power station. Owing to the expensive nature of the plant very stringent guarantees were specified to safe guard against undue losses and to secure the highest efficiency. Space will not permit the specifications to be given in detail here, but it might be mentioned that at the time of writing, the machines have been in service nine years without having been shut down for repairs of any description.

Each unit consists of two independent generators with-

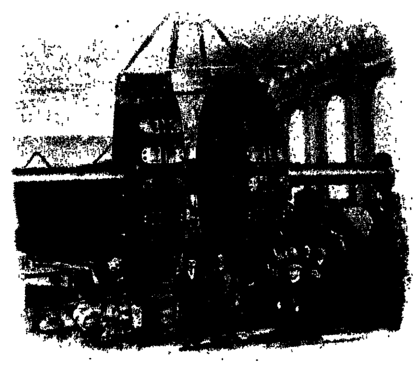


Fig. 173. Double rotor during erection.

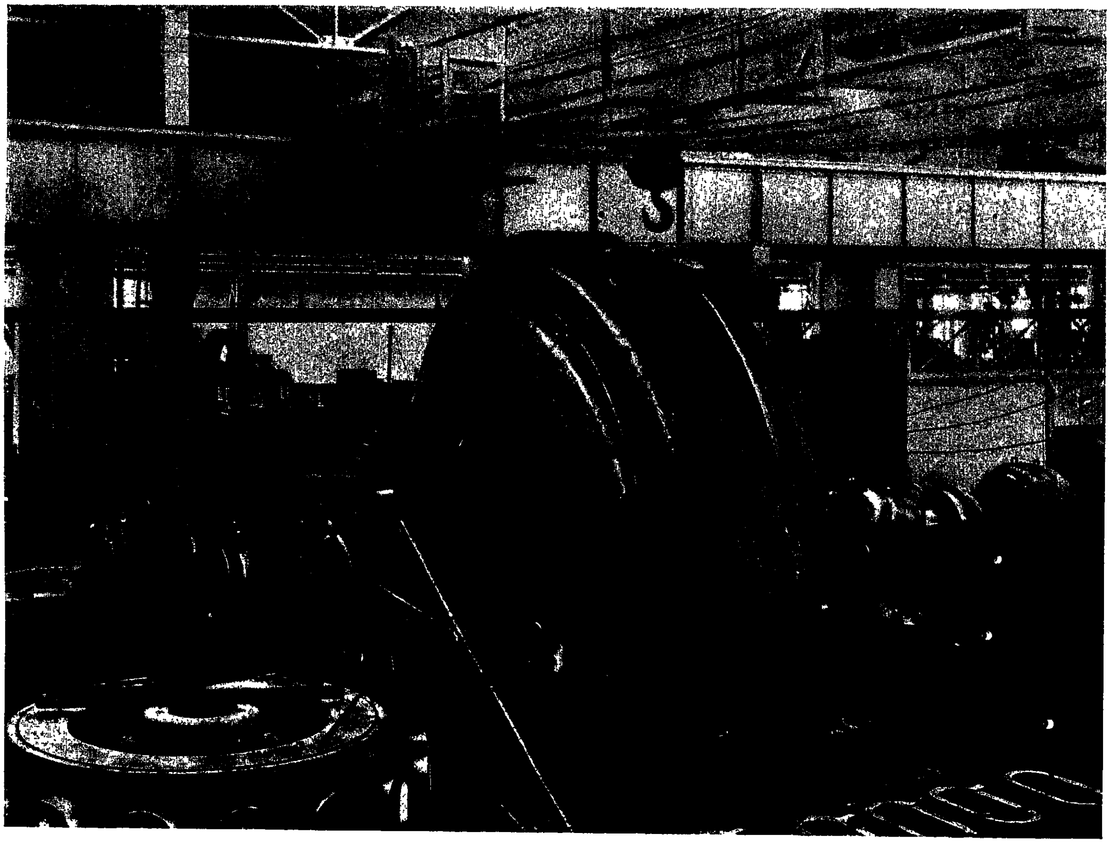


Fig. 174. A single generator erected for test.

out any electrical connection, erected on a common bedplate with casing connecting the two stator frames; the two rotors are on one shaft carried by two bearings. The machines are self ventilated by means of fan blades on the rotors, totally enclosed and connected with air ducts on each side of the lower half of the stator frames. The warm air is expelled into the stator frame, which is specially designed for this purpose, and can then escape into the power station through air holes or can be blown through air ducts in the floor, and thence outside the building. When these generators were designed very little data was available relating to totally enclosed machines of this type; this construction had however to be adopted owing to the large volume of air required to cool the machines effectively, — about 28 cubic metres per sec. Had open type machines been used, the temperature of the power house with all ten machines running would have become excessively hot for the attendants. When the question of cooling system was under consideration, it was decided to adopt the self ventilating type with fan blades on the rotors rather

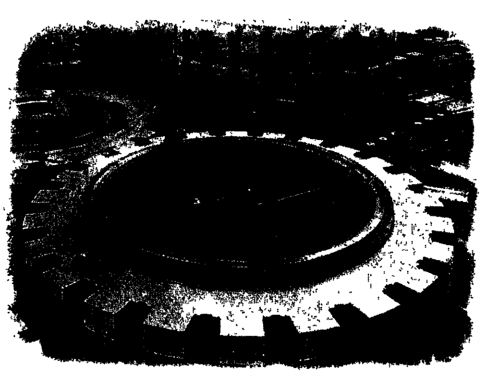


Fig. 175. Hydraulic test of rotor rings.

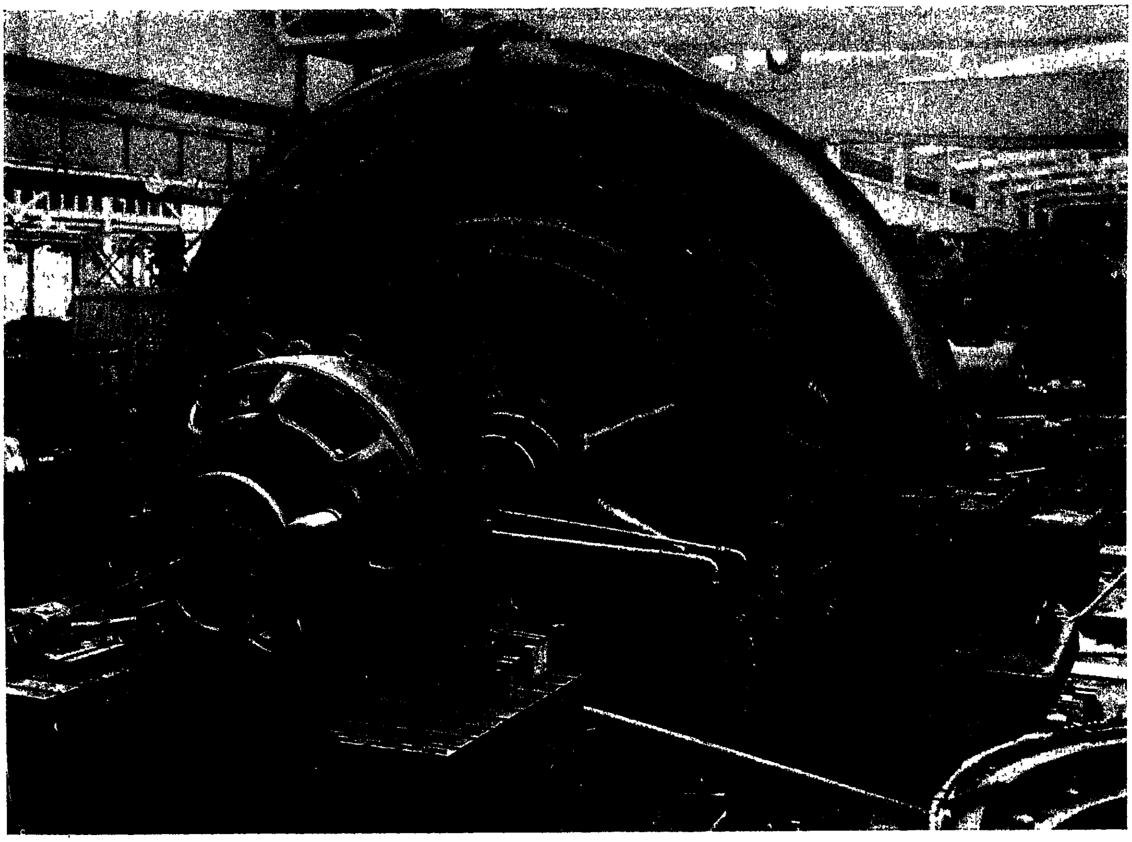


Fig 176. Generator and exciter in the test room.

than install a separate ventilating system for the plant. By this means the capital cost was somewhat reduced and the station was considered to be more immune from breakdowns without otherwise affecting the efficiency of the plant, regardless of the fact that the self ventilating effect of the generators was comparatively speaking considered somewhat wasteful.

In order to facilitate repairs the stators are arranged on the bedplates in such a manner that they can be moved axially, repairs can then be made to any of the stator or rotor coils without removing the top half. The stator frames are of cast iron in four sections to make transport possible. The end shields are also of cast iron which although increasing the weight of the machines, are more effective in keeping the noises produced by windage from the generator room.

The armatures cores, designed and built on standard lines, have an inside diameter of 4.15 metres, outside diameter 4.8 metres with an

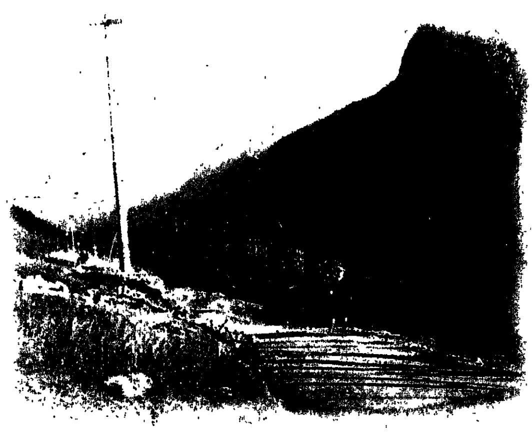


Fig. 177. Transmission lines near Vemork.

axial width of 0.85 metre. The windings are arranged in two planes, three open slots per pole per phase with four conductors per slot, each divided into several bars. The coils are held in the slots by fibre wedges. Each bar is cotton covered and impregnated whilst each conductor is insulated with micanite rolled on hot. These separately insulated conductors are then placed in a seamless micanite tube which is filled with an insulating compound and heated to ensure the expulsion of all air, making it impossible for ozone or nitric acid to form. After running for two years one of the coils was taken out for testing purposes but no deterioration could be found, although the machines had been subject to hard service.

The rotors have twenty four poles, the pole-pieces and pole-rings being in one piece of Siemens Martin Steel. The rings consist of several plates held together with bolts and the whole shrunk on to the centres. Very careful tests were made on all the individual parts of the machines, for example each of the rotor discs was subjected to hydraulic pressure equal to 25 % above the centrifugal forces exerted on them during the overspeed test. Owing to the high safety factor allowed in the design and to the good quality of material used, no permanent deflections could be detected. A radial cooling duct is arranged in the centre of the rotors, which insures efficient cooling of the central parts of the machines. The pole-shoes are laminated and held in position by bolts. The field-coils consist of 78 turns of copper strip wound on edge, insulated between turns with shellac and paper and from iron with prespahn, cylinders and washers. Owing to the great distance between bearings, the shafts are very heavy, having a maximum diameter of 0.7 metre. One end is furnished with a solid flange coupling for connecting to the turbine, the other arranged for bolting on the exciter armature. The shafts were counter bored the full length with hollow drills and the cores used for test purposes to make sure that the material was sound in every respect.

The flywheel effect of the rotating masses is about 7000000 kgms.

The bearings are lined with white metal, water cooled and have both ring and oil pressure lubricating systems. Off the different combinations possible with this arrangement, it was first decided to adopt the oil pressure system, where the oil is cooled in special tanks and forced through pumps into the bearings under the shaft; it was subsequently found that the oil rings with water cooling in the bearing shell worked satisfactorily without excessive heating and the former system is now held in reserve.

The field excitation is obtained from direct connected exciters designed for 220 volts 1200 amps and are large enough to supply one twin-generator; the current is taken to the generator field through two pairs of collector rings, one set of rings being placed at each end of the shaft.

Each twin-generator complete weighs about 240 tons; of this the stators weigh 115 tons, rotors and shaft 100 tons bearings and bedplate 25 tons. Each machine occupies a floor space of about 8.5 metres in length by 7.3 metres in width, the highest point on stator is 4.1 metres above floor level.

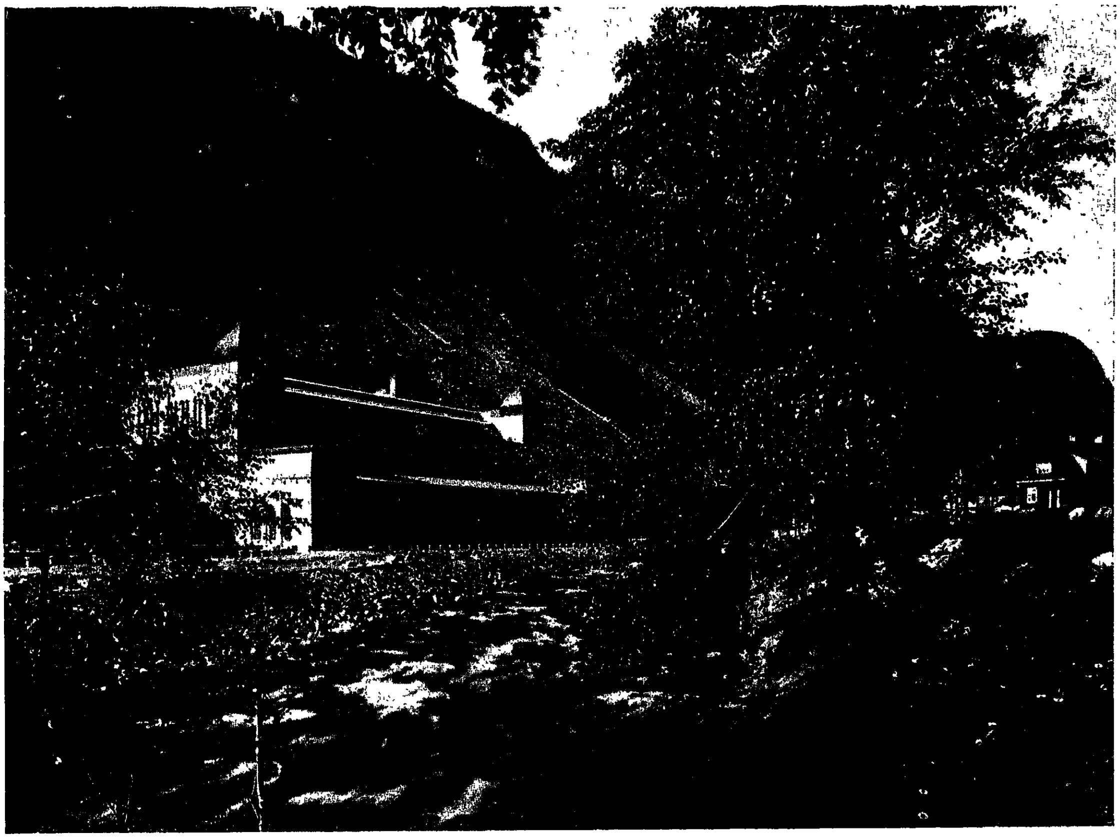


Fig. 178. Exterior of Saaheim Power station.

SAAHEIM POWER STATION.

AFTER the generators, previously mentioned, at Vemork had been in service a few years, and by their means the water power of the upper part of the Rjukan-falls had been utilised, an opportune time had arrived to develop the power from the lower part of the falls; consequently in 1913 the necessary work for this development was commenced and Asea received an order for the greater portion of the generating plant for this station. The order was placed during the summer and covered six generators with direct coupled exciters and switchgear, all to be delivered in the autumn of 1914 in order that the station could commence to supply power in the early part of 1915. Owing to the war the delivery time had to be extended, so that the first generators were not delivered until late in the spring of 1915 and the last in the early autumn of the same year. As previously mentioned, the generators

Fig. 179. Flumes at Vemork.

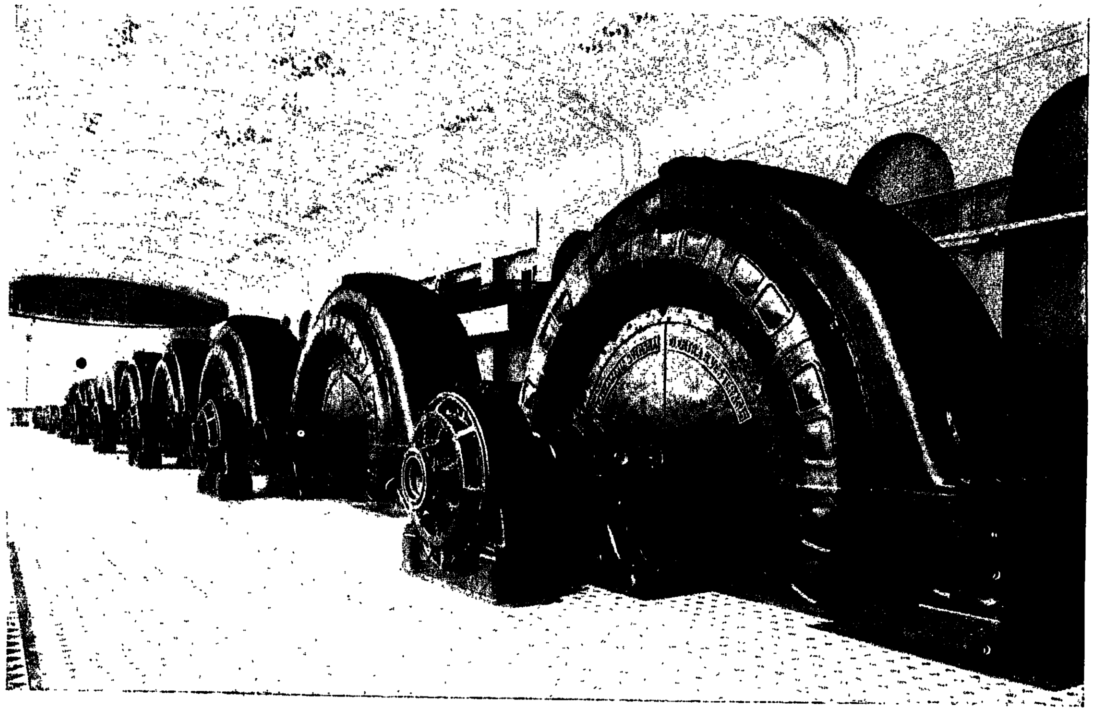


Fig. 180. Interior of Saaheim Power station, six Asea-generators with exciters.

are direct connected to the overhead transmission lines and so arranged that each generator feeds a separate line and its own group of furnaces. Each set of machinery from the forebay to the electric furnaces is a hydro-electric unit in itself.

After tests had been made with the generators at the Vemork station, in which one of the ten units was wound with a common armature winding for the two stators, so that the unit worked as one generator on the electric furnaces, it was ascertained that no disadvantages were experienced from this arrangement. It was therefore decided that the generators for this new station could be built as large of even larger than the ones at the Vemork station; the only limiting factors were transport difficulties, shop tools and erection facilities. The generators were therefore built for a continuous output of 18900 KVA — 9500 volts, 250 r. p. m., 50 cycles at 65 % power factor. These machines were the largest built by Asea and the largest of their kind in existence at that time. Like all large modern machines they are totally enclosed self-ventilated and fitted with fan blades on the rotor to draw air in and force it through the different parts of the machines and thence out through the air duct. The cold air is taken in through an air duct connected to the generator

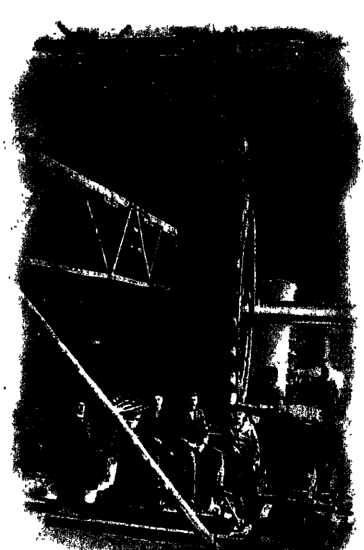


Fig. 181. Rotor of a Saaheim generator during erection.

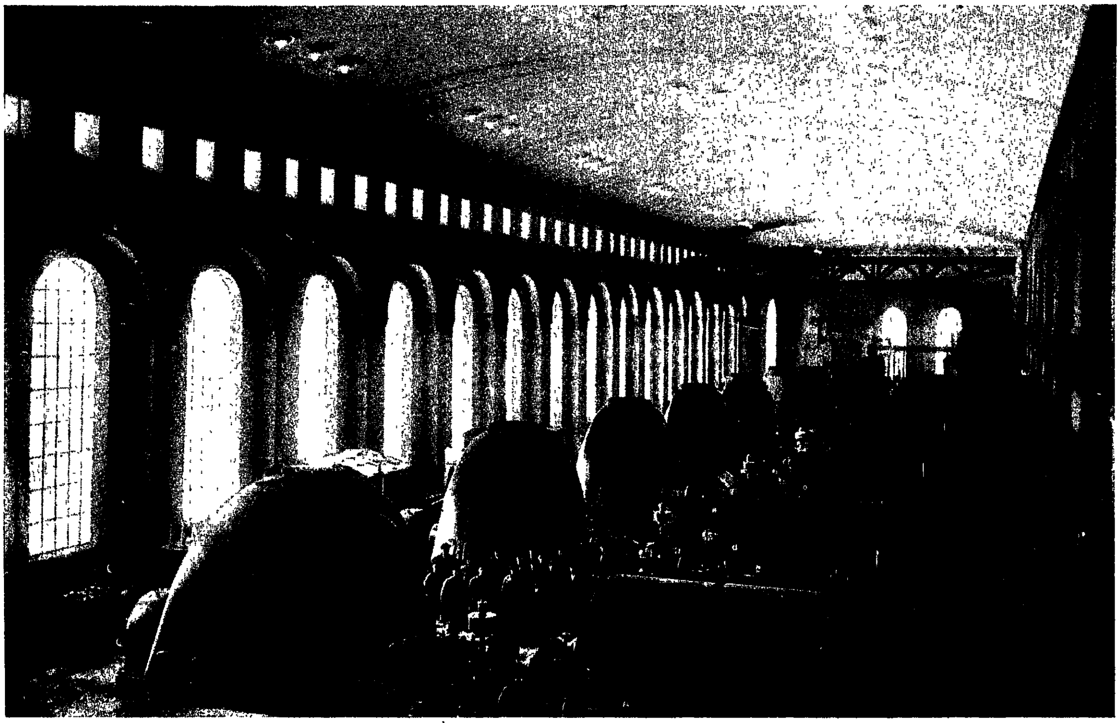


Fig. 182. Generators and turbines in Saaheim Power station.

pits and comes in under the shaft on the turbine side. After the air has passed through the machines, that is the rotor, stator laminations and the free ends of the coils, it is forced into the stator frame which is specially designed for this purpose and is then allowed to escape into the other side of the generator pit from which it is discharged into the warm air system. As it had been demonstrated in the older installation, with totally enclosed generators, that it was not advantageous to put openings in the stator frame to allow the air to escape direct into the generator room, these machines were designed with only a few openings in the upper half of the stator frames.

The stators are erected on bedplates fitted with guides so that they can be moved sideways parallel to the shaft in order that any necessary repairs can be made easily. The stator frames are made of cast iron in four sections. The greatest overall dimension (which is across the stator feet) is 8.1 metres and the outside vertical diameter of frame, including a support in the pit under the frame, is 7.3 metres.

The laminations are of high grade silicon iron, as very high efficiency was specified and guaranteed. At 100 % power factor and full load the efficiency is no less than 97.6 %. The stampings are made and secured in the usual manner their inside diameter

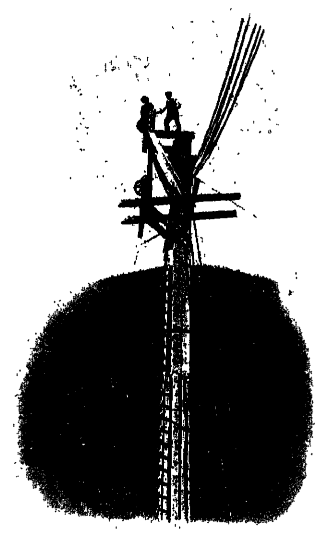


Fig. 183. Transmission line during construction at Saaheim.

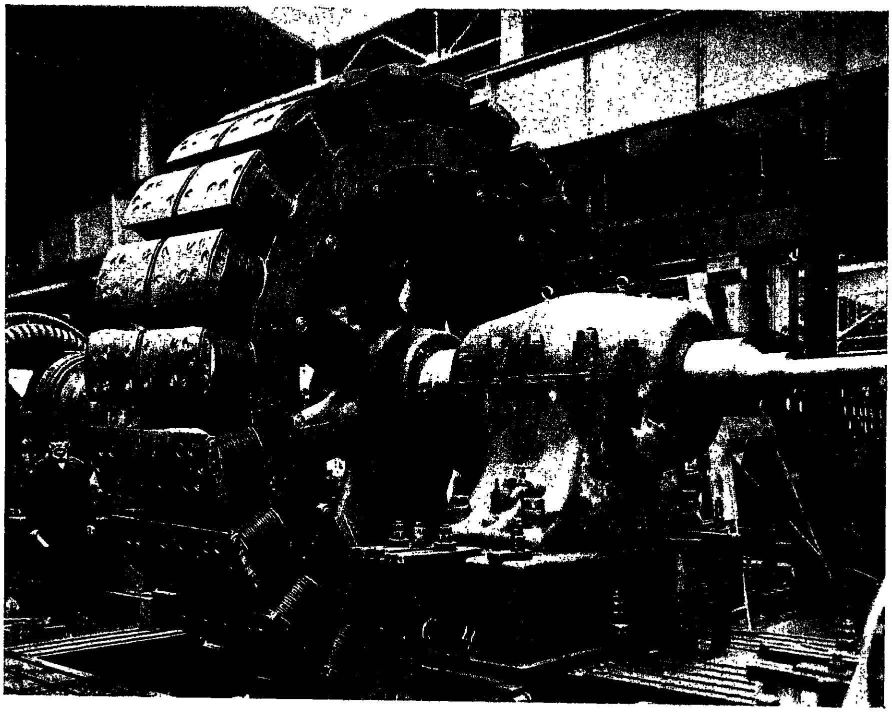


Fig. 184. Rotor erected for testing.

being 4.6 metres, whilst the outside diameter is 5.25 metres. The axial width of the laminations is 1,25 metres. Each generator had about 32 tons of laminations divided into 34000 segments which were built up by hand. The armature winding is a two coil winding, arranged in three open slots per pole per phase with two conductors per slot, each conductor consisting of several bars. The winding is insulated with micanite, as far as practicable, in order to fulfill the rigid specification for obviating shorts between turns. Although the normal working pressure of these machines is only 9500 volts, the specifications called for a test voltage of 30000, 50 cycles alternating current for 1 min. between phases and ground. After the machines were completed they were tested with 32000 volts for 3 minutes. Heavy brackets support the coils outside the laminations in order to prevent distortion in case of short circuits on the line. Short circuit tests were made with full load field current, and were withstood without the slightest detrimental effect to the windings.

The rotors have 24 poles and are made with pole-pieces and ring in one casting. To facilitate transport, and also to make sure that the material was sound throughout, the castings were made in several disc sections and held together with bolts. The sides of the rings are stepped and shrunk on to each other, the whole then being shrunk onto a steel centre. In the centre of the rotor there is a radial cooling duct allowing part of the cooling air to impinge against the central part of the laminations; by this means an even temperature is obtained in all parts of the machines preventing any danger of warm spots.

Fig. 185. Transmission lines near Saaheim.

The magnet wheel has eight hollow spokes and

is cast in one piece with the hub.

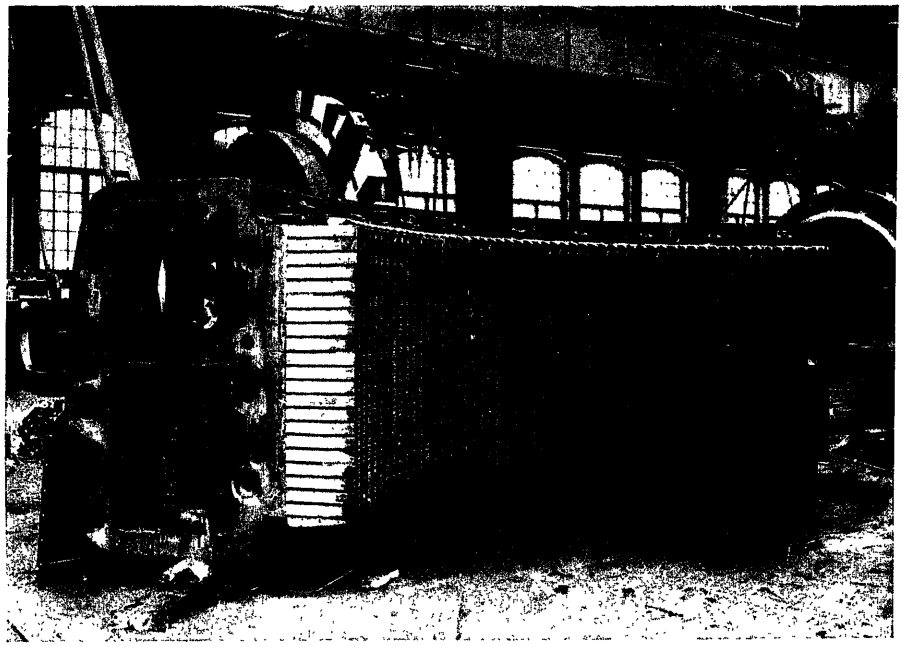


Fig. 186. Section of stator ready for winding.

The pole-shoes are laminated to prevent any excessive losses due to the open slots and are bolted to the pole-shoes. The pole-shoes hold the field winding in place, the latter being of copper strip wound on edge insulated in the usual manner and consisting of 51,5 turns per pole.

The shafts are no less than 7,74 metres long from turbine flanges to outside of exciters, have solid forged flanges for connecting to turbines and are counter bored their full length.

Collector rings of cast iron are placed inside the bearing at the turbine end; the connections between the field coils and collector rings are placed in a slot in the shaft and covered with iron wedges.

The bearings are babbit lined and water cooled with a combined ring and pressure feed oiling system. To prevent the circulation of parasitic currents in the bearings one of the pedestals is insulated from the frame and all pipe lines have their matallic continuity broken with insulated sections.

The field current is supplied from direct coupled exciters, the armatures of which are placed on the shaft extension of the generators with their field frames mounted on separate bedplates, and not attached to the generator bedplates according to the usual method in this class of machine.

By adopting this construction a section of the main generator shaft is free between the bearing and the exciter, so that should the bearing shell have to be changed, a jack can be placed under the shaft and the travelling crane used for handling the bearing parts.

Fig. 187. Saaheim by night.

Each complete generator weighs about 200

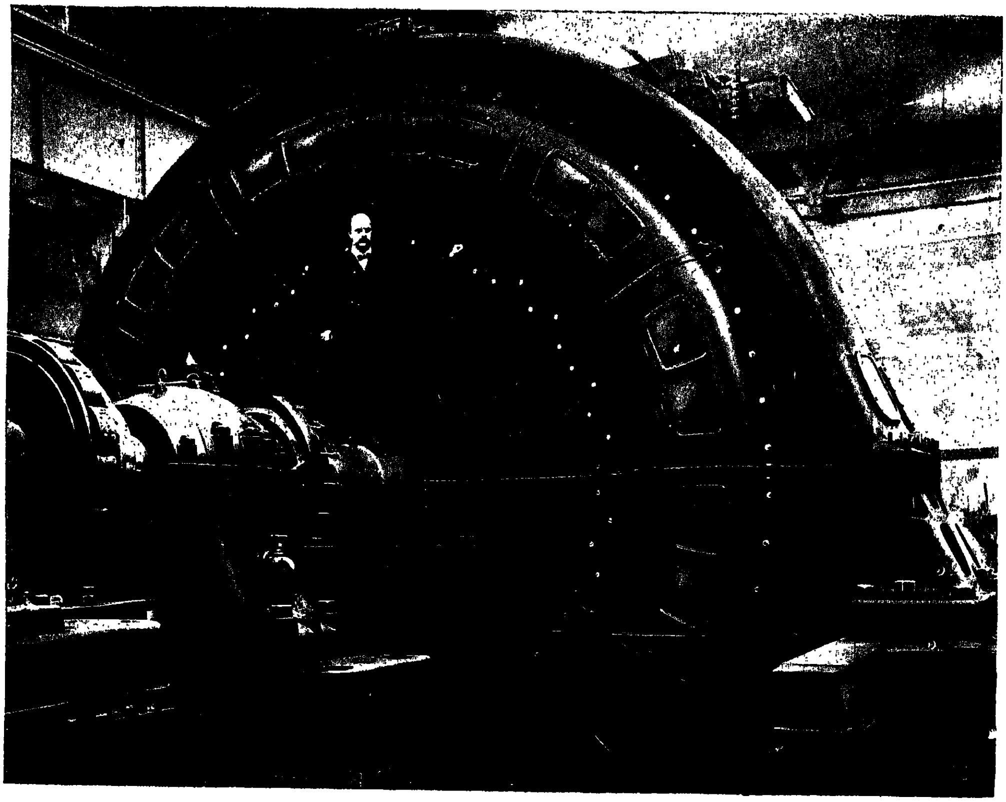


Fig. 188. Saaheim generator erected for test.

tons, of this about 90 tons is in the stator and 80 tons in the rotor and shaft. The bearings, bedplate, etc. making up the total.

Although considerable difficulties were encountered in testing these machines in the shop, all tests called for in the contract were carried out. To be able to make all the tests it was necessary to build a special two speed synchronous motor of 1500/650 HP, 380 volts, 500/250 r. p. m. synchronous speed, 50 cycles designed for direct coupling to the generators. All tests were made and proved that the rigid specifications in the contract had been complied with. The test motor was made for two speeds in order that it could be used to make the overspeed tests, the specifications calling for an overspeed of 450 r. p. m. for a duration of half an hour. The test showed that no changes had taken place in the rotor and was one of the severest tests which has been made in the Emaus shop; 1000 KW were required to run the generator during this test.

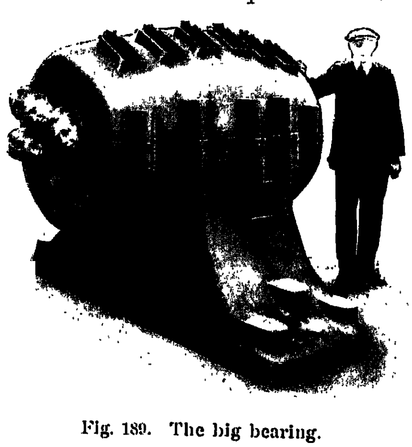


Fig. 189. The big bearing.

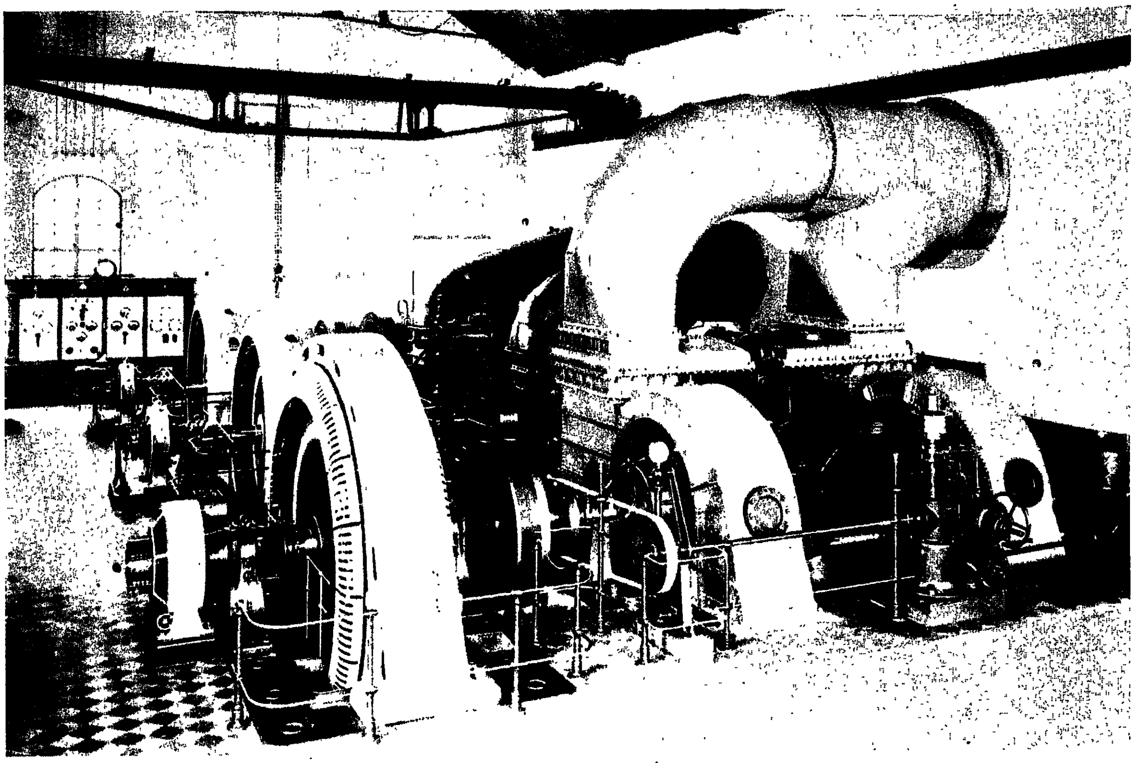


Fig. 190. Interior of the Power station with the first generator delivered by Asea in the foreground.

TINFOS PAPER WORKS.

AFTER the Birkeland-Eyde experiments for producing nitric acid from the air had advanced to such a degree that production on a large scale could be undertaken, the first works were erected at Notodden and the requisite power purchased from the Tinfos paper works which had a hydro-electric plant at Tinfos not far from Notodden on the river Tinnelven. The station had only 2 three-phase generators of 500 KVA each, but as it had to supply power to the paper mill and also to a carbide plant at Notodden the capacity of the power station had to be increased. In 1904 Asea received an order for a generator having a capacity of 2830 KVA, 5150 volts, 250 r. p. m., 50 cycles at 67 % power factor arranged for direct coupling to a 2750 HP water turbine. The production of nitric acid showed such promising results that all the available power was soon utilised, and after a period of only two years the Tinfos Company were obliged to instal another generator, for

Fig. 191. Tinfos Paper-mills, Notodden.

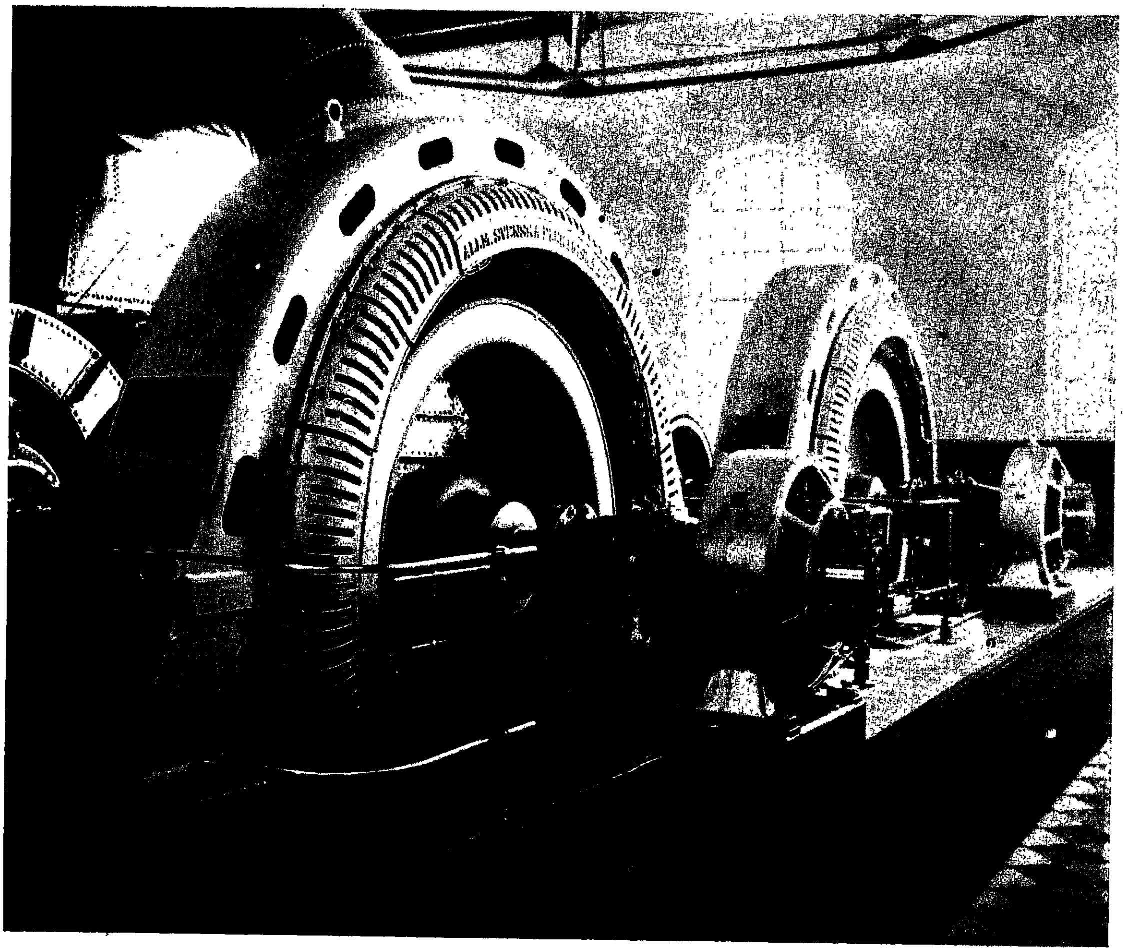


Fig. 192. Another view of the Power station. Both 2830 KVA units running.

which Asea also received the order. This machine was to be an exact duplicate of the first one and was delivered in the latter part of the summer of 1907. The order included a direct coupled exciter, switchgear for the first set installed and several auxiliary machines.

The first of these machines was the largest generator built by Asea at that time and the first to be tested at the new Emaus shops. The generator is of the open type mounted on a unit bedplate, stationary armature and rotating field on horizontal shaft carried in two bearings. The shaft extends beyond the bearings at each end in order to allow for coupling to the turbine on one end and exciter armature on the other; the exciter carcase is mounted on a separate bedplate.

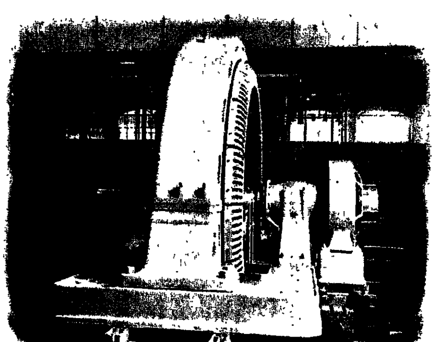


Fig. 193. The first generator at the conclusion of its tests.

The stator frame is of cast iron in two sections and has one detachable foot so that it can be lowered on to the rotor and turned with it in order that repairs

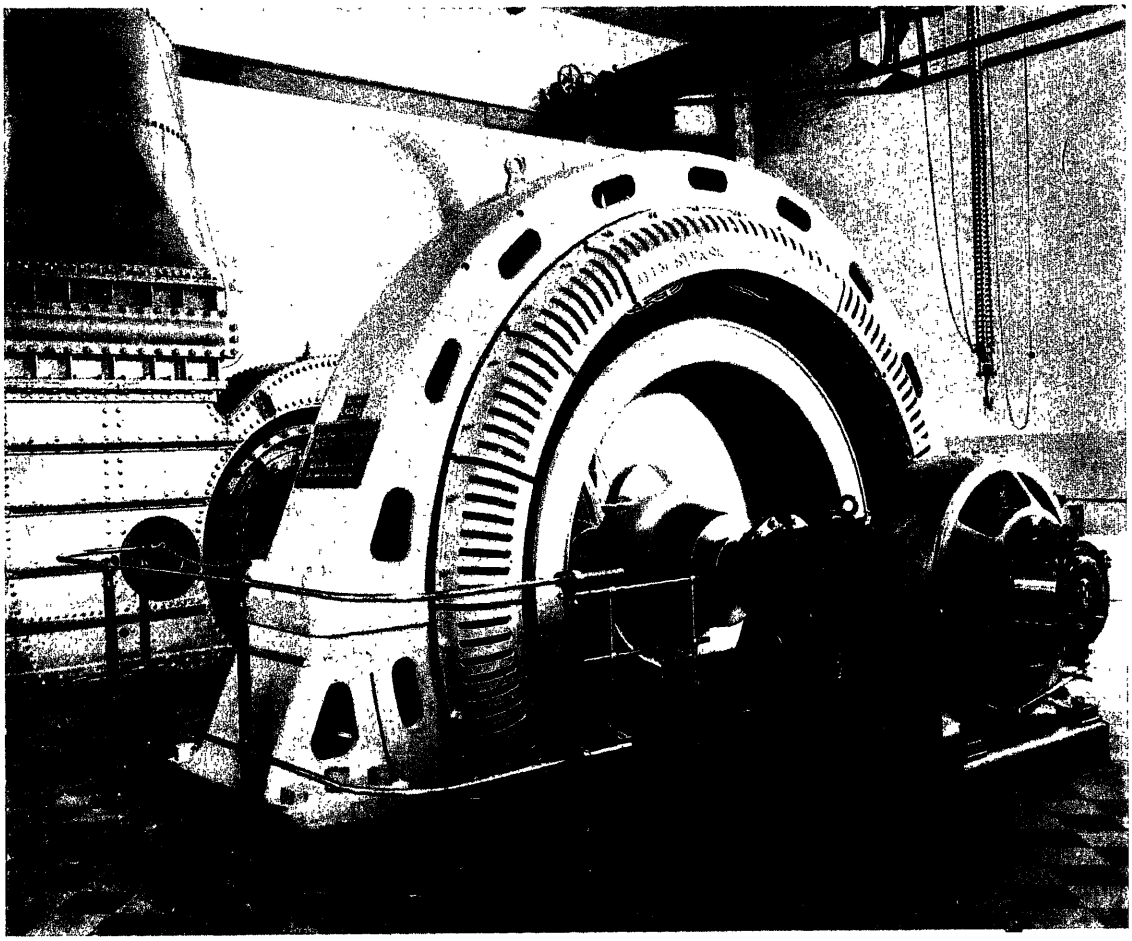


Fig. 194. The second Asea generator during acceptance test.

can be made to the lower half of windings. The stator frame is cast with air openings on the periphery and has no openings on the sides. The laminations are dovetailed into the stator frame in the usual manner and held together with flanges put on under pressure, and are divided into sections by radial air ducts 15 m/m wide. The inside of stator is 3 metres diameter and has 288 half-open slots, in which a three plane coil winding is placed. The coils are insulated from the frame by micanite tubes, the free ends are insulated with empire cloth, etc, and are protected by cast iron end shields.

The rotor is constructed with an inner ring of cast iron, cast with the hub, and an outside ring of steel; this latter ring also has the pole-pieces cast with it. The steel ring is shrunk on the cast iron ring which is of the same outside diameter as the steel ring on one side, by which means the necessary flywheel effect was obtained for the turbine regulation.

The pole-shoes are solidly bolted to the pole-

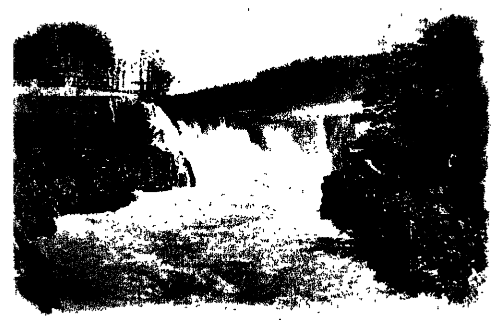


Fig. 195. Tinfos.

pieces and hold the field coils in position, the latter being wound of copper strip on edge and insulated in the usual way. The connections between field coils and collector rings are made according to standard practice and the rings are placed inside the bearing and not on the outer end of the exciter shaft as in older types.

The flywheel effect of the rotating masses is about 780000 kgms.

The bearings are of the ring oiling type arranged for water cooling, so that even at speeds considerably above normal their temperature can be kept within resonable limits.

The machine occupies a floor space of 3.95 metres axially 5.45 metres across stator feet, the highest point above floor level is 2.94 metres and centre line of machine 0.8 metre above floor. The generator pit is 1.65 metres deep. To improve the ventilation an air duct is connected with the pit to the outside of the building, allowing cold air to come in direct to the machine.

The weight of the complete machine is about 45 tons, of this the stator weighs 17.5 tons and the rotor and shaft 19.1 tons, the remainder being in the bedplate, bearings, foundations bolts, etc.

Fig. 196. The dam at Tinfos.

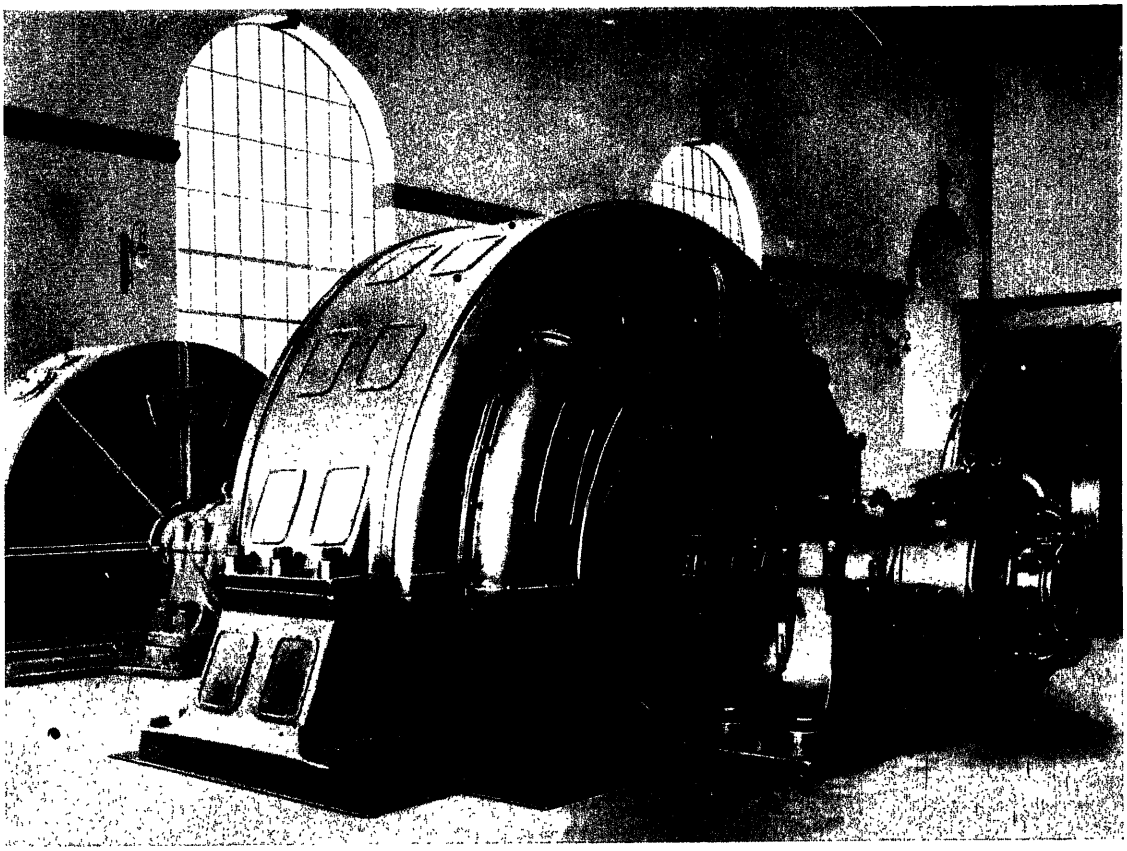


Fig. 197. Interior of power station showing exciter end of one of the three-phase generators.

A/S BJÖLVEFOSSEN.

AMONG the few large hydro-electric stations designed and built during the war, Bjölve is one of the largest. This station was built during 1917 and the early part of 1918 for the »Det Norske Aktieselskab for Elektrokemisk Industri», through its subsidiary company the A/S Bjölvefossen in the same part of the Aalvik at Hardangerfjord in West Norway. Water is taken from the watersheds above, from whence it is conveyed in the customary manner to the forebay, and from there through banded steel tubes down to the power station located at the foot of the mountain close to the bank. The useful head is 890 metres which is one of the highest in the world. As the water volume is only about 5 cubic metres per sec. it is transformed into useful energy, at the present time, by means of single

Fig. 198. Power station and carbide works at Aalvik.

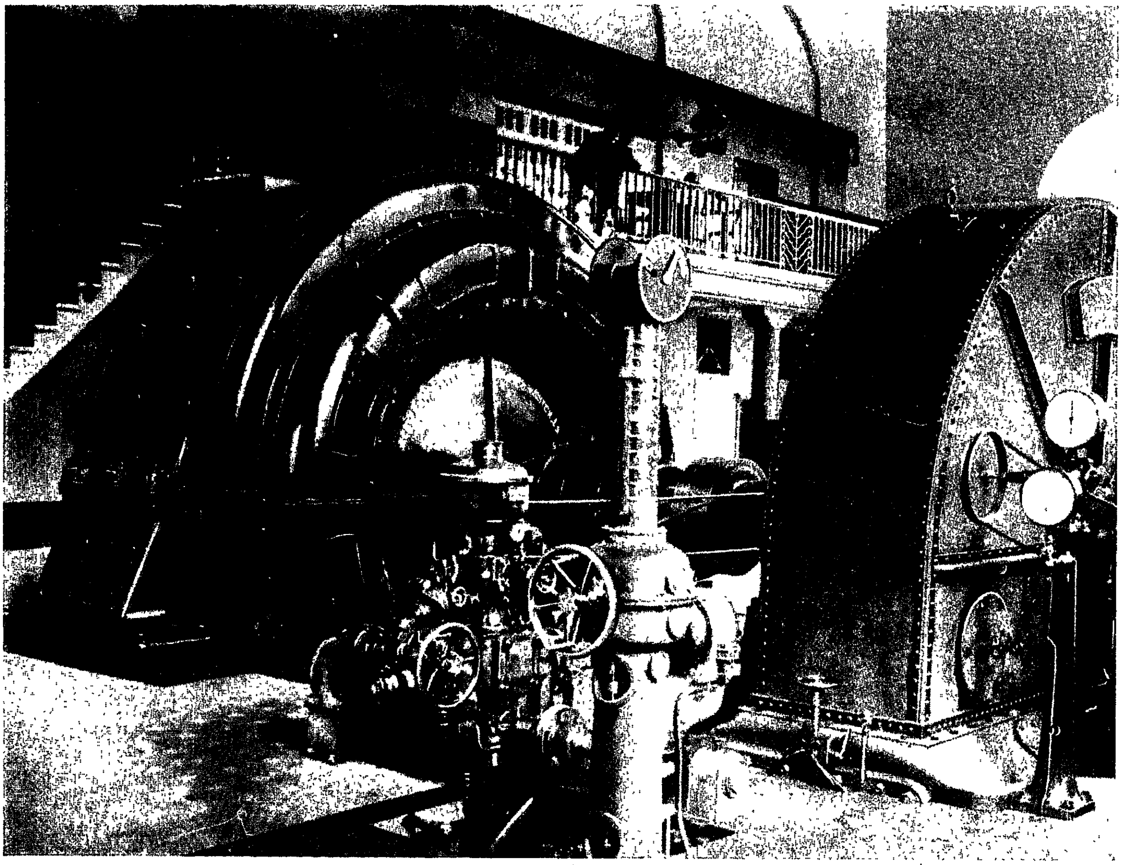


Fig. 199. Turbine end of one of the three-phase generators.

Pelton wheel turbines of an aggregate of 37000 HP. This power is converted into electric energy by three direct coupled three-phase generators driven by single wheel turbines and designed for 10750 KVA, 12000 volts, 375 r. p. m., 50 cycles, at 80 % power factor. Close to the power station are the carbide works owned by the above company and the power from the hydro-electric station is here utilised for producing carbide by means of electric furnaces.

Fig. 200. Part of the flume on the mountain side.

In the spring of 1916 Asea received an order for three generators with direct coupled exciters, switch-gear, auxiliary machinery, storage battery, etc. Owing to the extremely difficult conditions under which the station had to be built, brought about by the war, it was not put into service until August 1918.

The 3 three-phase generators are, with the exception of a few minor details, made according to Asea's standard design for large water turbine driven generators. They are totally enclosed machines with stationary armatures and rotating fields on horizontal shafts with solid flanges for coupling to the turbines.

The stators are split horizontally, made of cast iron and designed to form a receiving chamber for the hot air coming from the rotor and stator windings. From the stator frames the air is led out through two openings in the lower half and thence through ducts to the station warm air system. Cold air is taken into the generator pits (which are entirely closed in) through air ducts in the floor and passes into the machines below the shafts through special air connections in the cover plates. The air is filtered before it enters the air duct to prevent any dust from the carbide furnaces gaining access to the machines. The cover plates over the rotor and the stator coils are of standard design, made of cast iron fitted with removable inspection covers for cleaning and other purposes. Cover plates are also arranged at the back of the stator frames, which can be removed to allow warm air to enter the generator room direct.

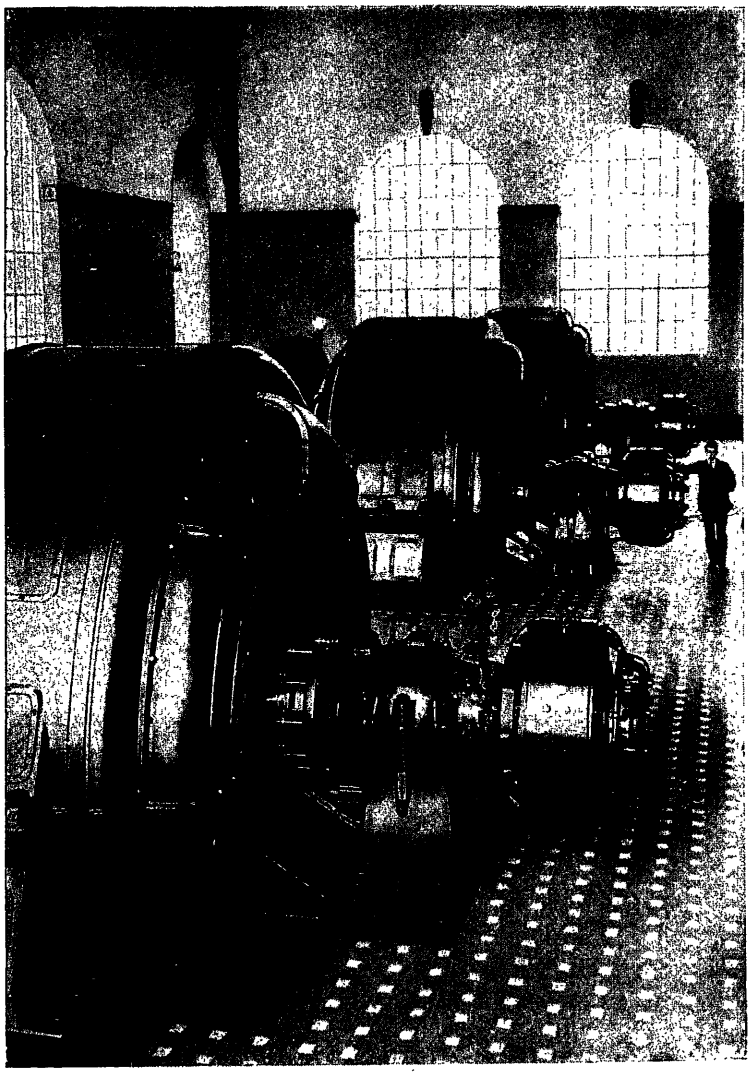


Fig. 201. View of the three units.

The armatures are built up of standard sheet laminations dovetailed to the frame and held together by means of clamping rings. The diameter at the air gap is 2.8 metres and total axial width 1.3 metres. Due to the small number of poles, the depth of the laminations is rather great, the outside diameter being 3.45 metres.

The armatures have a two plane coil winding in 144 open slots, with seven conductors per slot. The coils are held in the slots by fibre wedges and are well braced where they project beyond

Fig. 202. The power station situated at the foot of the mountain.

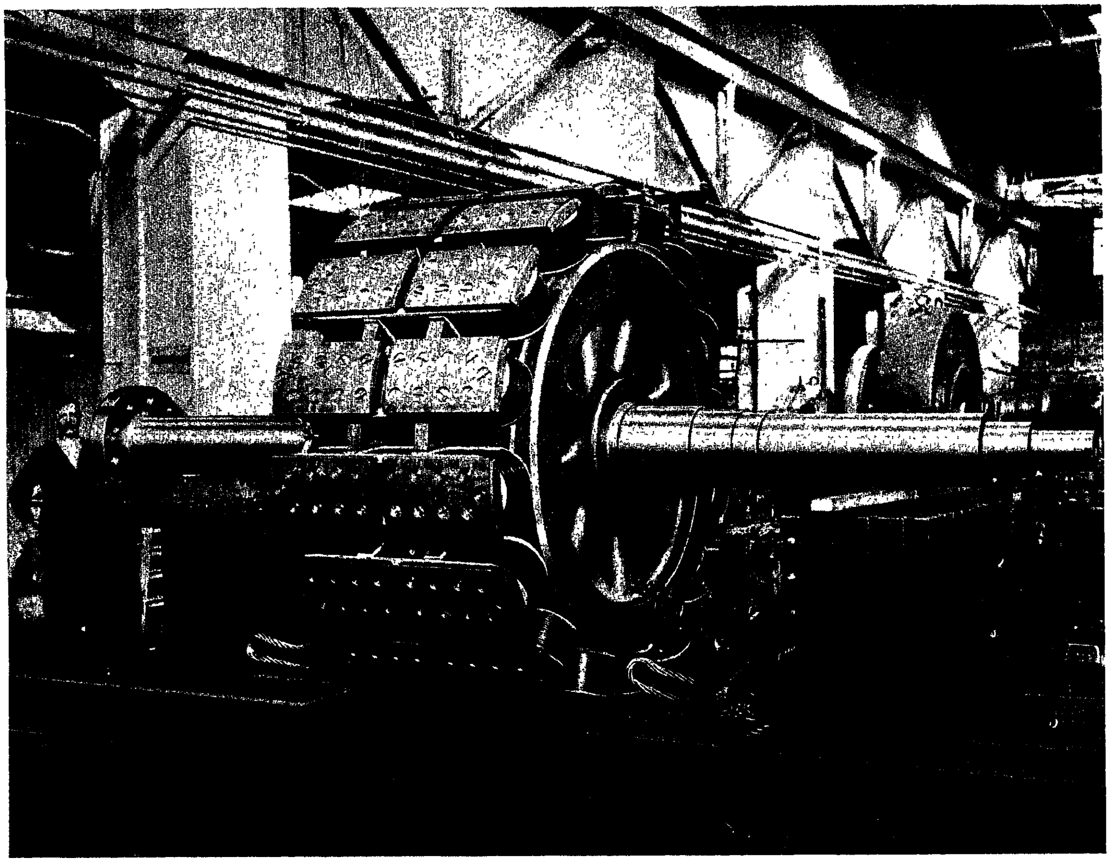


Fig. 203. One of the Bjölvefos rotors.

the laminations. The insulation between individual conductors, and also between conductors and iron is principally micanite. The free ends of the coils are insulated with empire cloth, except at such places where the coils are braced, where micanite washers and plates are added. The four ends of the windings (one for each phase and one for the neutral point) are as usual located at the bottom part of the stators.

The stators cannot be moved axially as is usually the case with Asea's large generators. Should repairs be necessary to the rotors, the top halves of the stator frames have to be lifted off, after which any part of the windings can be easily repaired. To repair the bottom half of the stators the feet have to be removed and the stator rotated on two sets of rollers in the generator pits, the stator frames having tracks on the outside periphery. This design saves floor space but is not as convenient as the usual arrangement in case of repairs or inspection.

The rotors are of standard construction and have sixteen poles, with poles and ring cast of steel in one piece. The rotors are divided by a radial air duct and the two halves are shrunk on

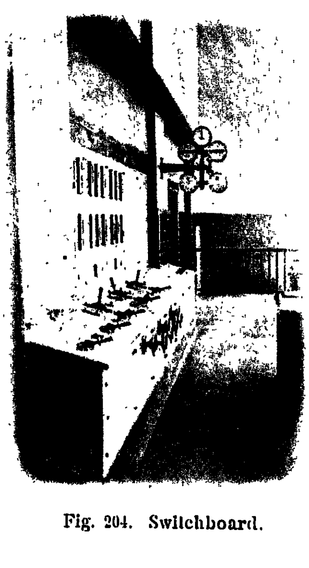


Fig. 204. Switchboard.

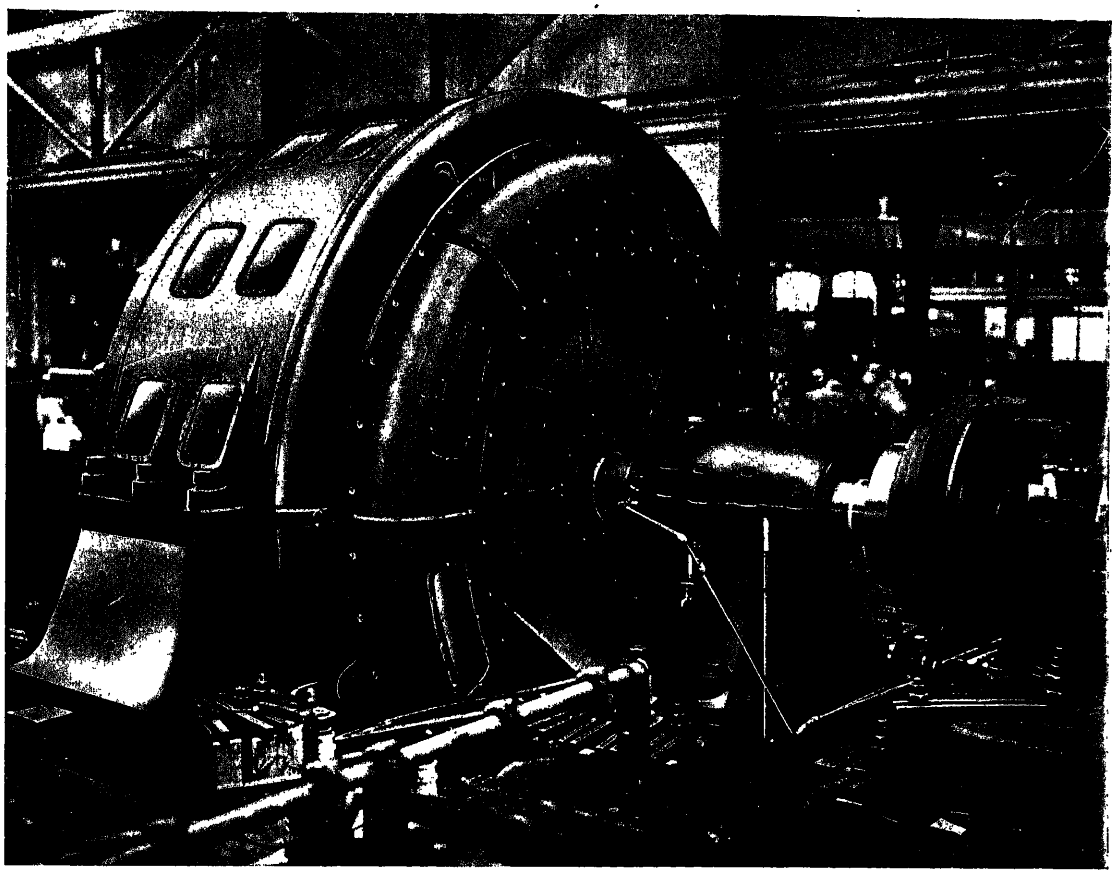


Fig. 205. One of the Bjölvefos generators during test.

a cast iron centre, which is also divided into two radial sections. The two halves are held together with bolts running parallel to the shaft. The radial cooling ducts were put in, to allow some of the relatively cool air to impinge against the central parts of the machines; owing to their comparatively great axial width. This precaution was taken to avoid any possibility of the central parts of the machines becoming overheated.

The pole-shoes are of cast steel with laminated faces and are secured to the pole-pieces with bolts. The field winding consists of 52.5 turns per pole of copper strip wound on edge, insulated between turns with paper and shellac and held in place by the pole-shoes. The field coils are fitted with the special cooling devices according to standard practice on large generators. Fan blades are fastened to the side of the rotors to assist ventilation. The shafts are of standard construction with solid flanges for direct coupling to turbines and have forged extensions for the reception of the exciter armatures. The shafts are mounted in two

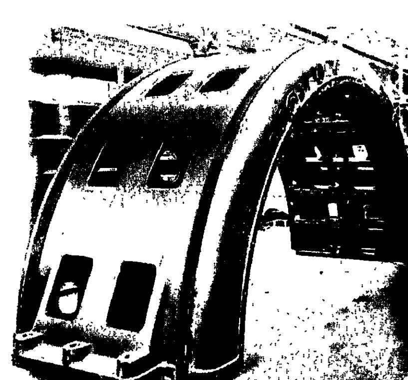


Fig. 206. One of the stator halves.

bearings of the oil ring type with water cooling in the shells; one pedestal is insulated from the bedplate to prevent the circulation of parasitic currents.

The fly-wheel effect of the rotating masses is 2950000 kgms.

The field current is supplied by direct coupled exciters, the armatures of which are pressed on to the main shaft extension, the field frames being supported on the bearing pedestals. No resistance is placed in the generator field circuit, the field current being regulated entirely by the exciter field rheostats.

Each generator occupies a floor space of 6.4' metres from the turbine coupling to the outside end of the exciter shaft, 5.9 metres across the stator feet and from floor level the highest point of the stator is 3.38 metres. The centre of the generators is 1 metre above and the pits are 2.4 metres below the floor level.

The total weight of each machine is about 110 tons, of this 50 tons is in the stator, 40 tons in the rotor and shaft and the remaining 20 tons in the rest of the machine. The weight of each exciter is about 2 2 tons.

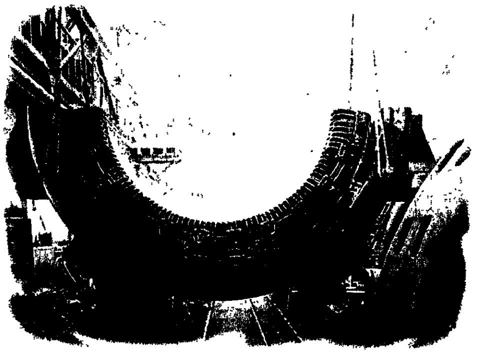


Fig. 207. Finished under-half of stator being transported to the test room.

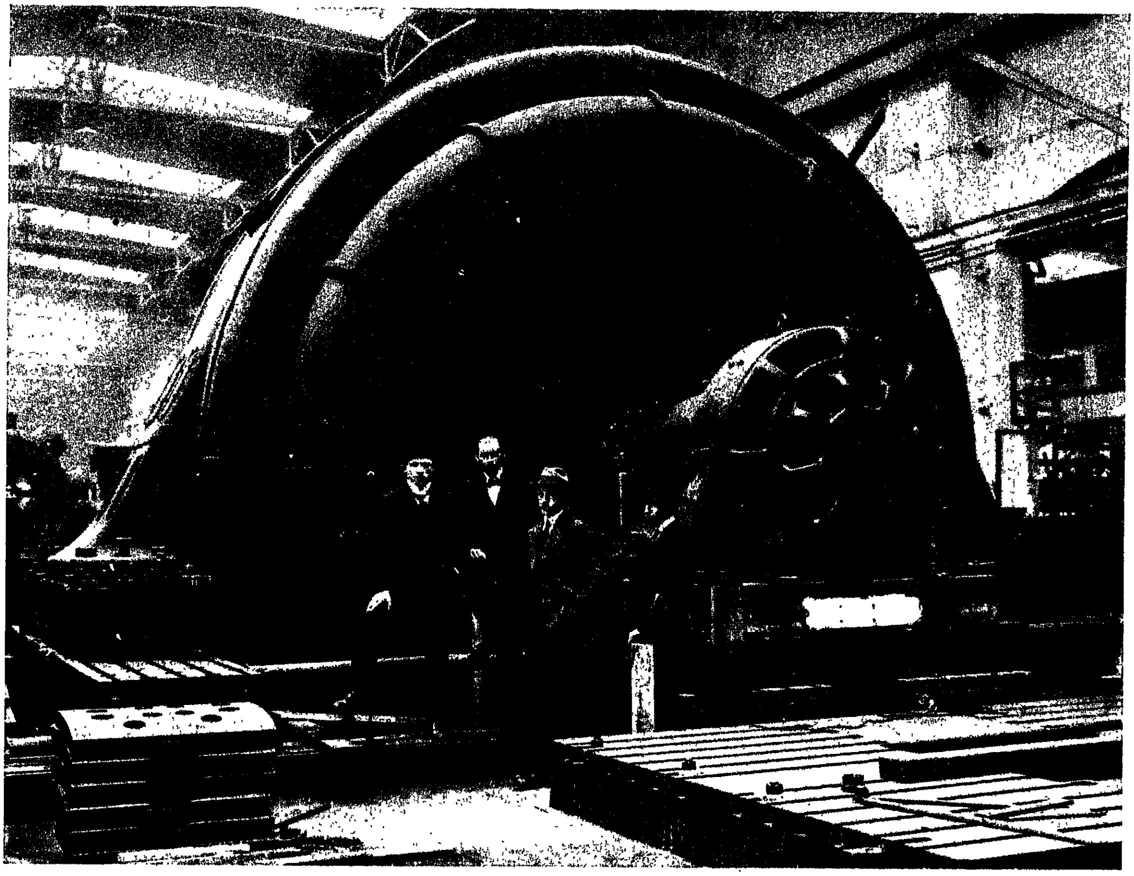


Fig. 208. The first Glomfjord generator after acceptance test.

NORWEGIAN STATE POWER STATION AT GLOMFJORD.

NORWAY, the foremost of all European countries with regard to hydro-power possibilities, has water falls which can be developed for hydro-power purposes at relatively low costs, from its Southern border line with Sweden to the Arctic coast and North East boundary with Finland.

Of these falls, only those in the South and South Western portions of the country have so far been seriously developed; the large falls in the North have not yet been harnessed to any great extent. This condition of affairs is however rapidly changing and some of the Northern falls are now being utilised in a small way compared with the available

Fig. 209. The head of Glomfjord.

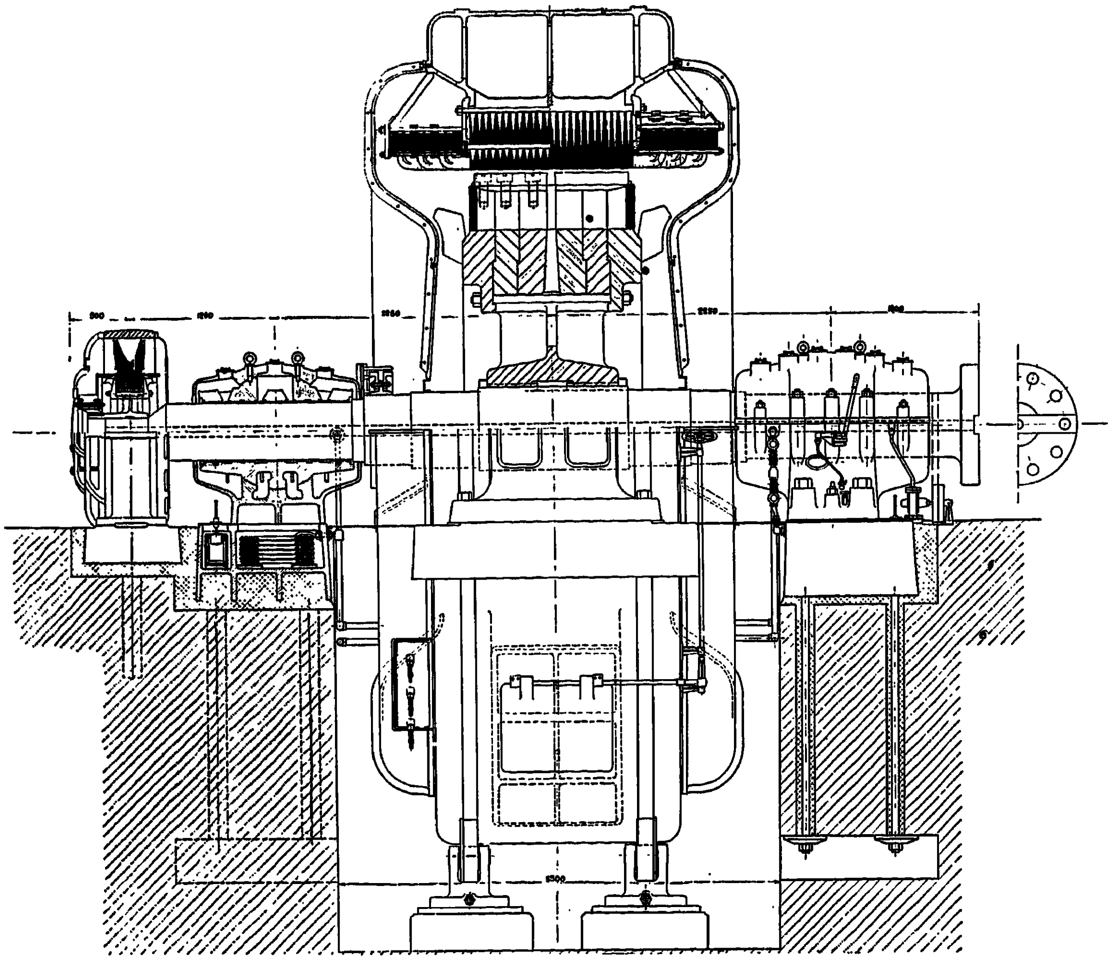


Fig. 210. Section of Glomfjord generator and exciter.

power, while others have power plants under construction or estimates are being got out for projected schemes.

At present the largest and most important of these is the installation at Glomfjord.

This power station is located at the head of Glomfjord, which runs into the Arctic Ocean in North Helgoland, South of Lofoten, about 30 kms north of the Arctic circle. The water is collected from a water-shed having an area of about 250 square kilometres, the greater portion of which is covered by the big "Svartisen" glacier. The average useful volume of water is 25 cubic metres per sec., but in order to obtain an even flow, a reservoir of from 5000000 to 6000000 cubic metres is necessary. This is accomplished by means of lake Storglomvand, located 512 metres above sea level,

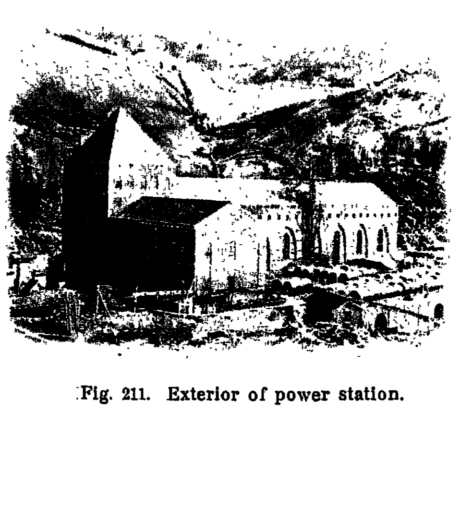


Fig. 211. Exterior of power station.

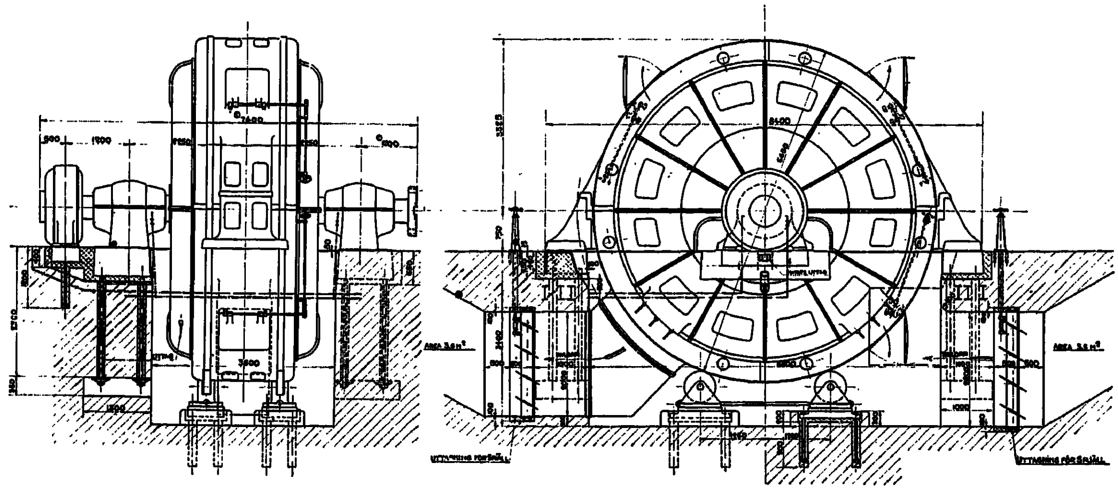


Fig. 212. 22000 KVA generator for Glomfjord.

through which the water from the water-shed passes. A dam 6 metres high has been thrown across the outlet of this lake and a cut 16 metres below the dam gives an available head of 22 metres for regulating the water supply. From Storglomvand to the small Navervand lake, an adjustment of 8 metres in the water lever is available by means of a dam. The Storglomvand reservoir has a capacity of 570 million cubic metres, while Navervand has only 14 million cubic metres.

For the first 3 kms the water is taken from Storglomvand in an old river bed, and thence through a tunnel 2.2 kms long to lake Novervand from which it is again taken through a tunnel 3 kms long to the forebay, from whence it flows through flumes to the turbines in the power station. The effective head of water is approximately 450 metres. In the first instance only two machines, each having a capacity of 25000 HP, were installed, but the remaining available water will be utilised by installing four more units, probably of somewhat larger capacity, at some future date.

The falls were surveyed in the early part of 1913 and the preliminary work for the power scheme was commenced in the autumn of 1915 by the A/S Glomfjord, which company owned the water rights in Tykanaaga, the river into which Storglomvands originally flowed. The construction work was carried out with such energy, that Asea received an order for the first electrical equipment for the extensions in the summer of 1916. During the construction period the Norwegian government purchased the power station and its water rights; the A/S Glomfjord retains only its works and part of the property on which the proposed town is to be built, and purchases the power required for its works from the State.

Power is transmitted from the power station — which is built at the foot of the mountain on a narrow strand — by means of overhead lines,

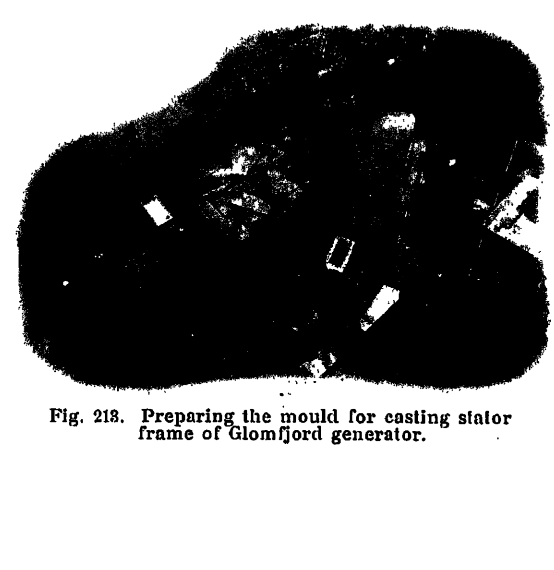


Fig. 213. Preparing the mould for casting stator frame of Glomfjord generator.

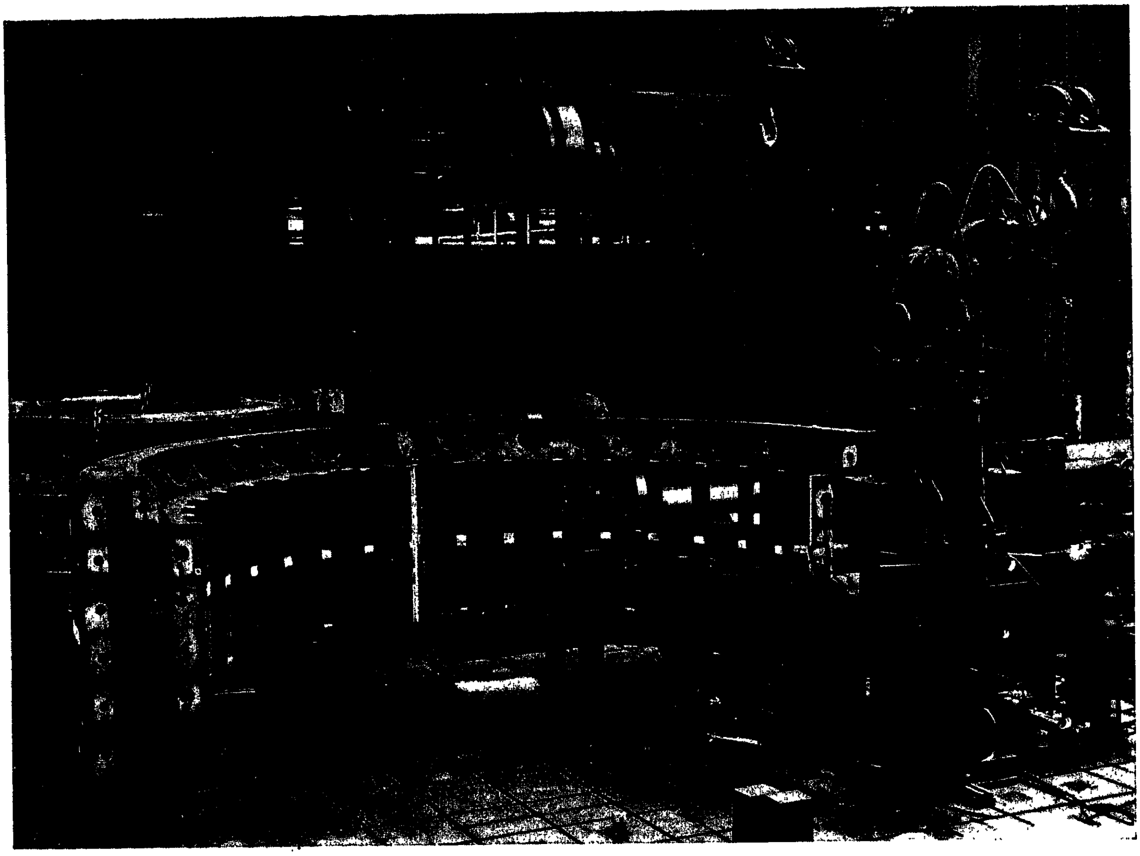


Fig. 214. Machining stator frame.

which first pass through a tunnel 1.2 kms long and then on concrete poles past the old Glaamen farm, at which place the town of Glomfjord is springing up, into the industrial district at Haugvik.

At this latter place the main part of the power generated will be used in the production of zinc, but later on for the manufacture of calcium carbide and iron. The Norwegian government intends to instal a plant for extracting salt from the sea water but will also distribute power to the surrounding districts.

When laying out the station it was originally intended that the whole installation should be put into service in 1918, but owing to the difficulties encountered during the war, this date had to be postponed to the summer of 1919.

The work undertaken by Asea in the extension to this big power station, consisted of the supply of two three-phase generators with direct coupled exciters, transformers, motor generator sets, storage batteries and all the necessary switchgear.

The two three-phase generators are the largest

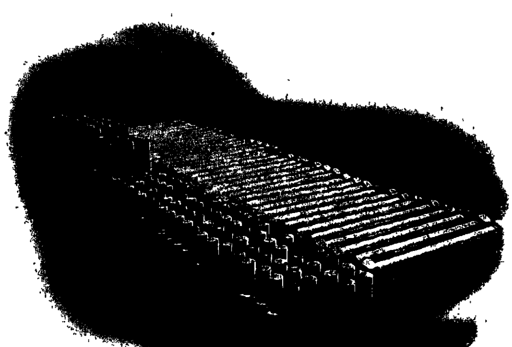


Fig. 215. Bolts for Glomfjord generator.

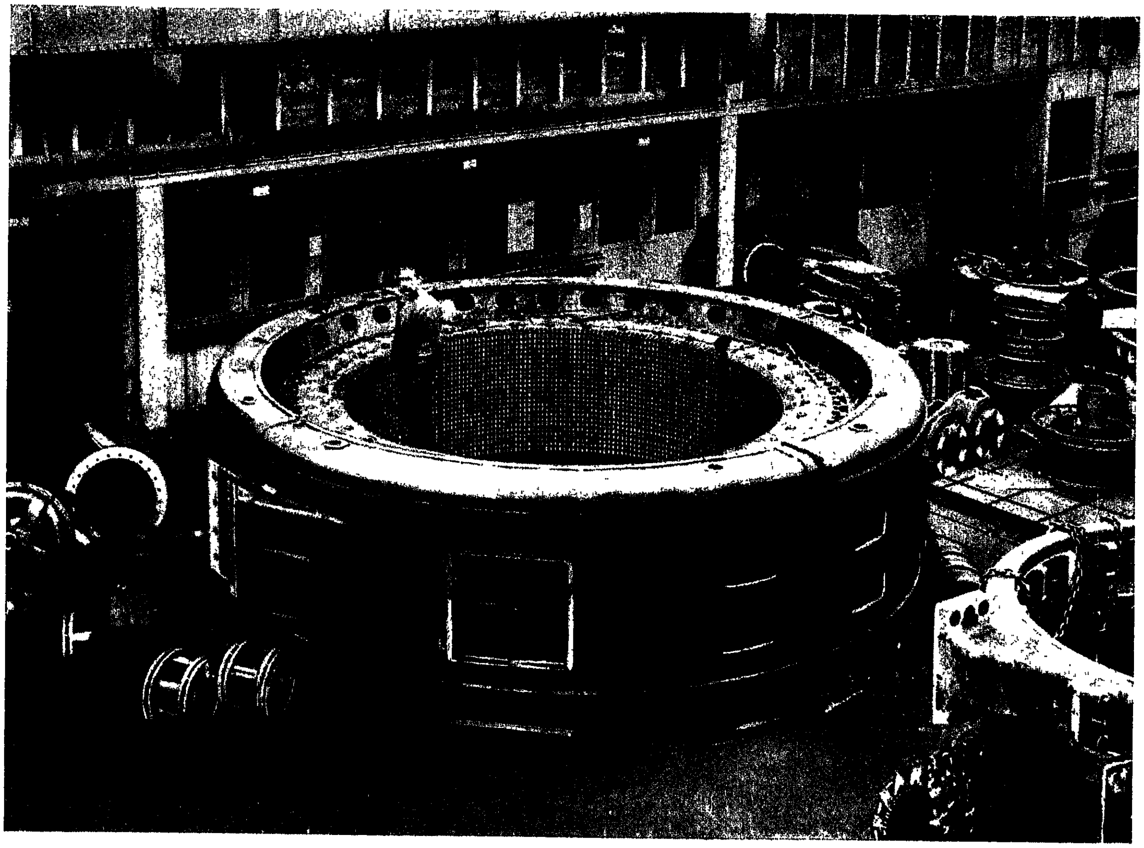


Fig. 216. Stator ready for winding.

which have been built in Asea's shops, and at the time of their construction were probably the largest direct coupled water turbine sets in the world. They are designed for a continuous output of 20000 KVA, 15000 volts, 300 r. p. m., 25 cycles, at 80 % power factor, at which load a temperature not exceeding 50° C. is stipulated; the machines can moreover be continuously loaded to 22000 KVA without the temperature exceeding 65° C., this corresponding to an absorbed energy of 25000 HP.

The generators are constructed with stationary armatures and rotating fields on horizontal shafts with flange couplings for attachment to the turbines, and shaft extentions for the reception of the exciter armatures.

The generators are totally enclosed and fitted with intakes and outlets for the cooling air. The rotors have fan blades attached for forcing the air through the cooling ducts in the machines and also through the air intake system. The ventilating system of this installation is

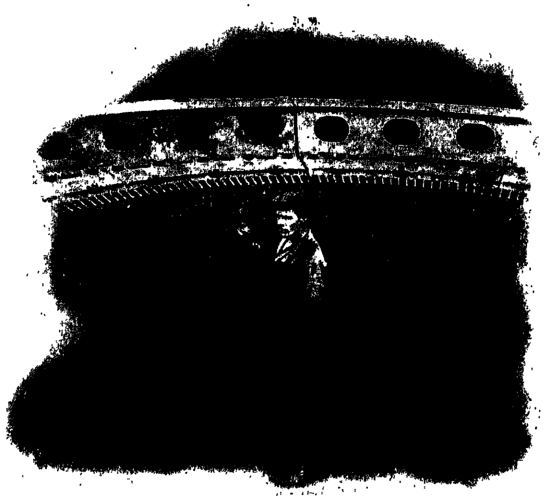


Fig. 217. Stator laminations.

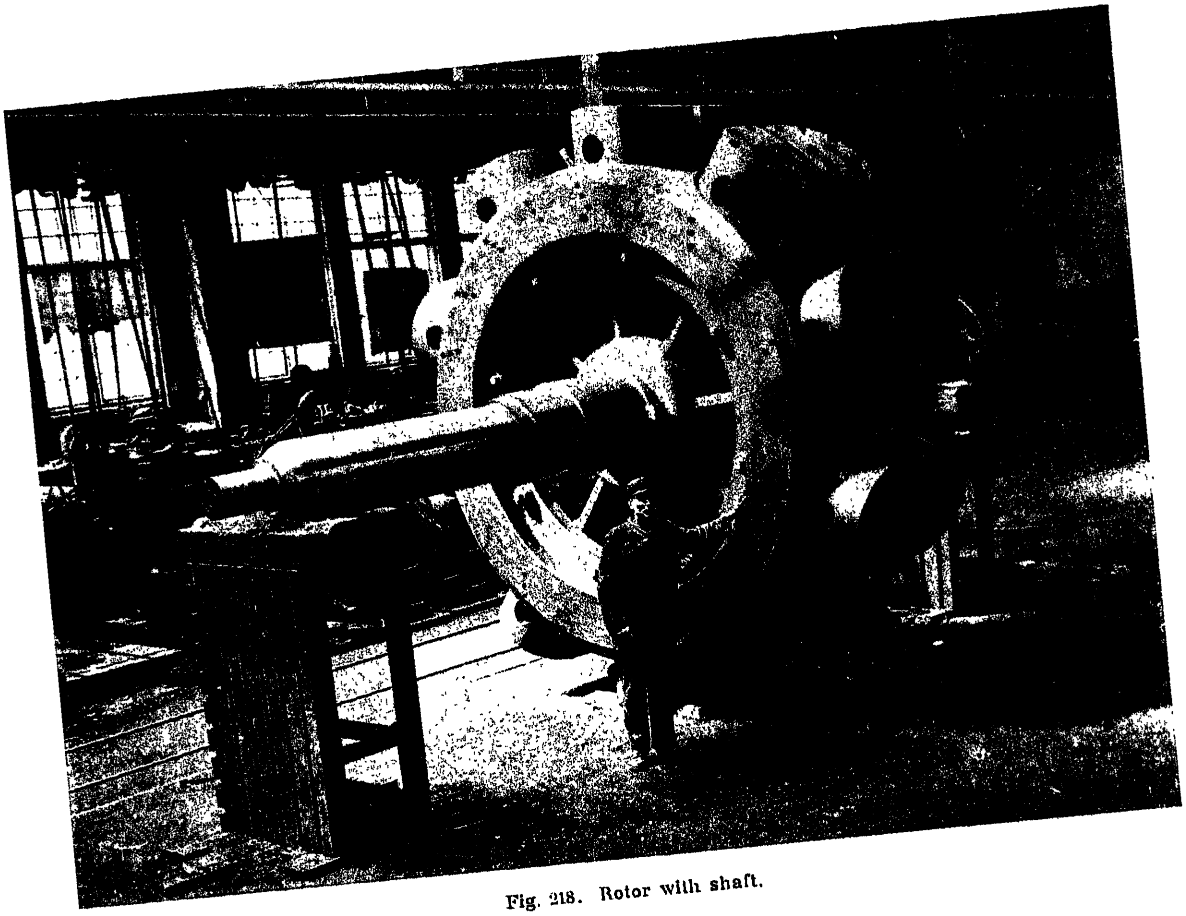


Fig. 218. Rotor with shaft.

somewhat different to normal arrangements, wherein provision is made for an air inlet main with branches to each machine and a main air outlet passage to which the branches from the different machines run. In this particular plant, each generator has an independent system. The air is drawn direct from the outside by the fan blades on the rotors and after first passing through an air filter, is taken through a short passage under the floor, direct to the generator pits (which are completely covered in) from whence it is forced through two inlet pipes one on each side of the stator frame, to the centre part of the machines and projected against the windings and laminations, the hot air then passes into the stator frames, which are specially arranged for this purpose. From the stator frames the air can be taken through movable covers in the end plates, into the generator room, or can be passed into the pit to be mixed with incoming air or taken through the air outlet duct connected to the bottom half of the stators outside the building through a duct leading to the end of the power station. It can also be passed to the air filter and mixed

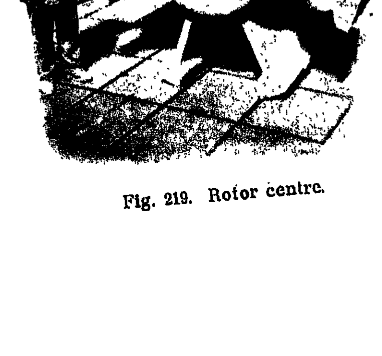


Fig. 219. Rotor centre.

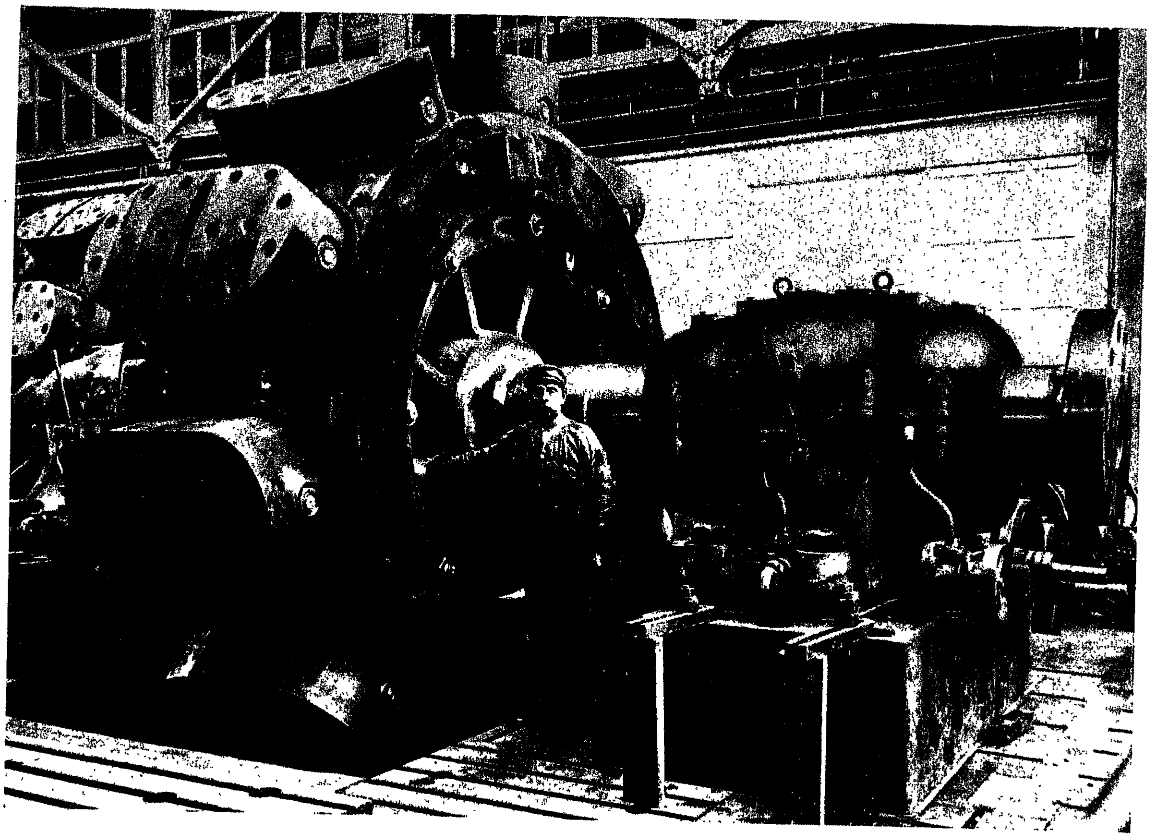


Fig. 220. Rotor being assembled.

with the incoming supply of fresh air. Shutters and dampers are arranged on the generators and in the air passages to allow distribution of the warm air in any of the above mentioned ways. The volume of air to be handled in this way is rather large, as 30 cubic metres per sec. are required for each machine at full load.

The stator frames are of cast iron divided into four sections to facilitate transport. The weight of each section with laminations and winding, is about 23 tons. The periphery of the stators is arranged with machined strips to engage with rollers placed in the pits (see fig. 212), so that they can be turned after one of the feet has been detached; in this manner any part of the stators can be easily inspected or repaired. There are several cover holes on the outside cylindrical face of the generators through which the warm air can either enter the generator room or the generator pits; doors or shutters are fitted to these cover holes and arranged so that they can be opened from the floor level, this also applies to some of the inspection covers which as a rule are bolted down and only used at the time of erection or when

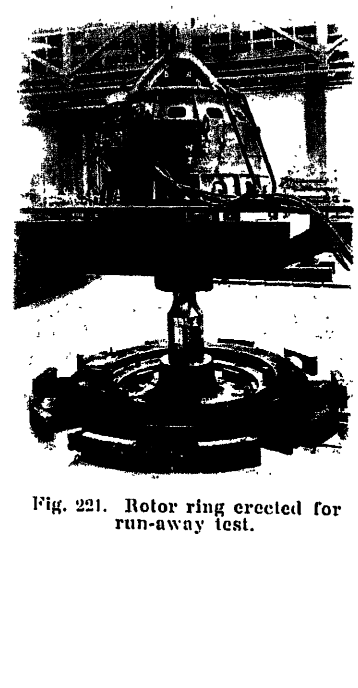


Fig. 221. Rotor ring erected for run-away test.

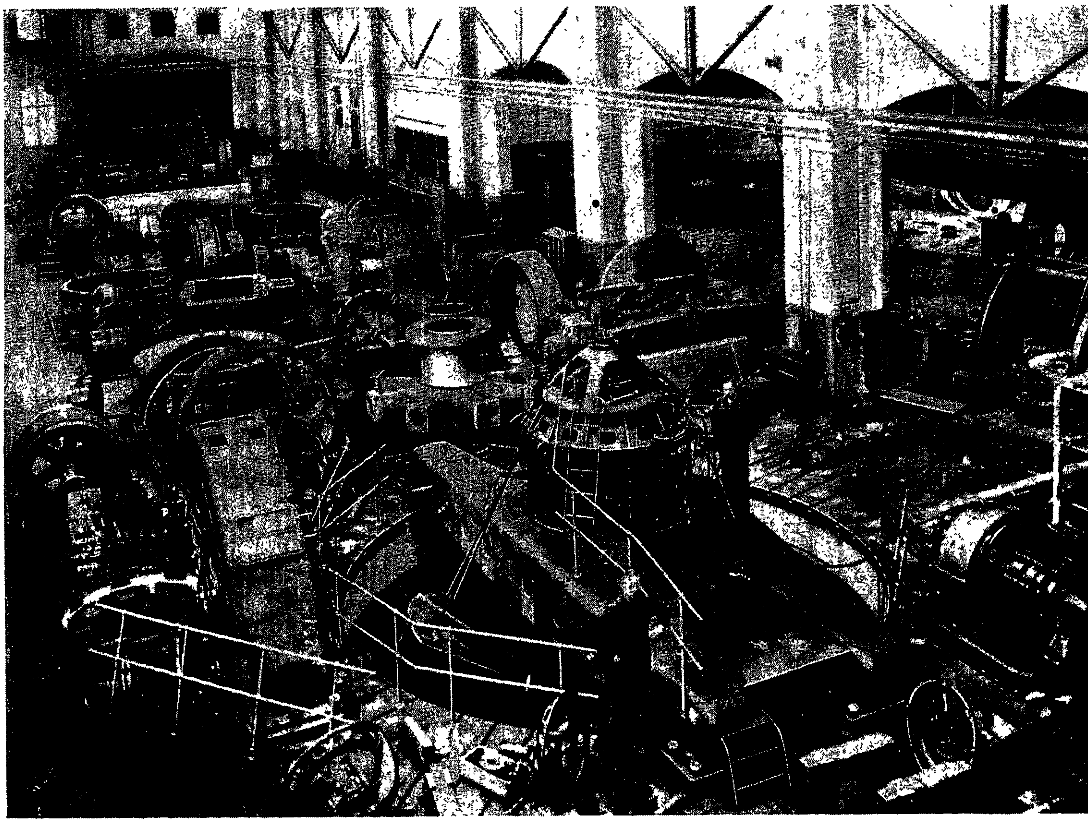


Fig. 222. Preparing for run-away test. Rotor parts assembled in test pit on vertical shaft.

repairs are necessary. There are no openings on the sides of the stator frames, with the exception of those used during erection and through which lifting bars are placed. Owing to the heavy weight of the sections no eyebolts were fitted, the lifting tackle being fastened to the above mentioned beams.

The generators are enclosed by means of cast iron end plates made in sections, these serve the dual purpose of enclosing the machines and protecting the windings. Cast iron was used for these plates in order to more effectively deaden the inherent noise of the machines, at the same time allowing a more pleasing design to be used. The cover plates are made with small inspection openings provided with doors to enable the coils to be cleaned and inspected.

The armature laminations are held in the stator frame in the usual way with dovetail construction, and are held together with flanges applied under pressure and secured by bolts passing through the back of the laminations, these bolts are well insulated from the iron. The flanges are made with fingers corresponding to the teeth in the laminations,

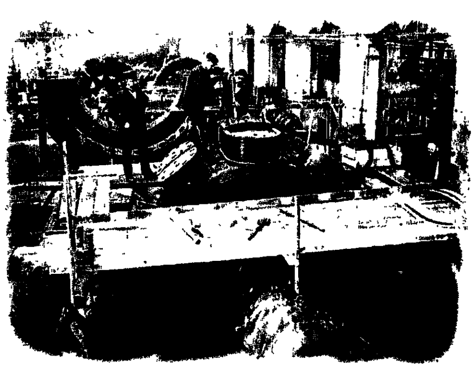


Fig. 223. Pole-pieces being bolted to rotor ring.

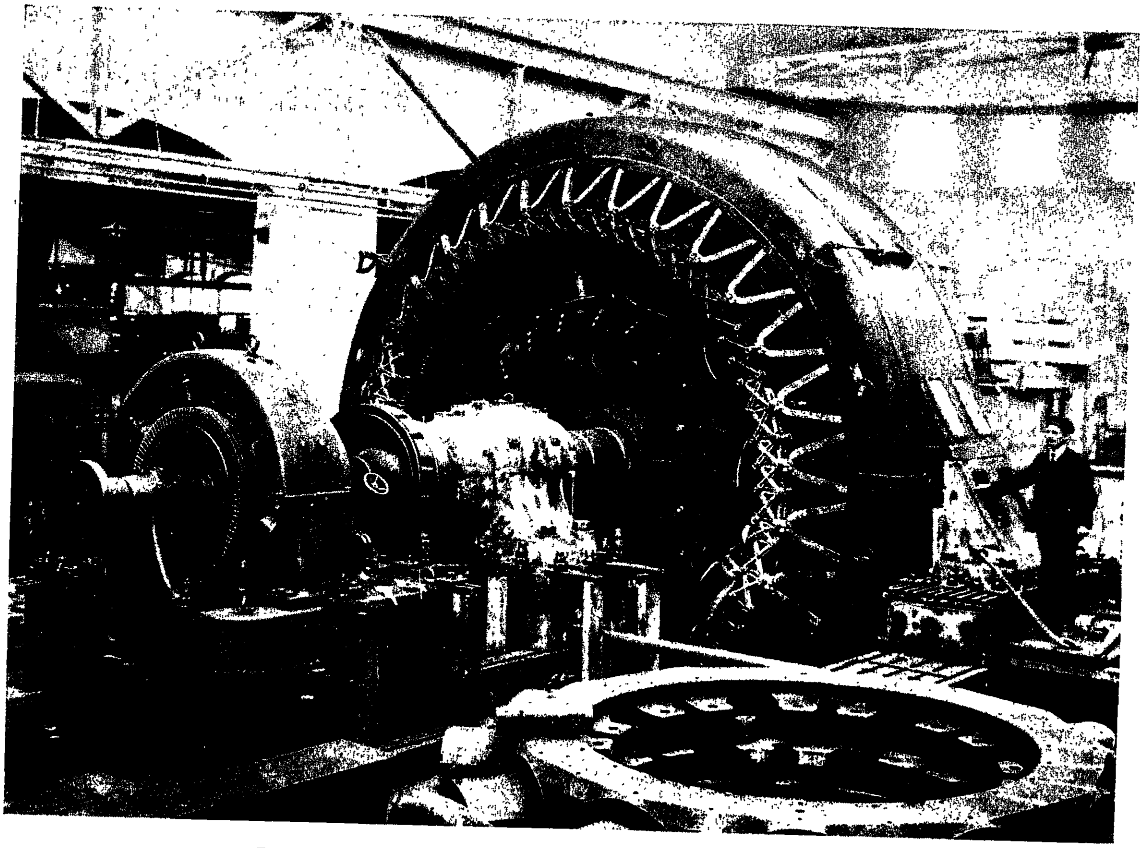


Fig. 224. First Glomfjord generator during erection for testing.

thereby securing uniform pressure on the whole of the laminations from the outside periphery to the airgap. The laminations are divided up into several sections by air ducts, allowing good ventilation and preventing any hot spots which might otherwise arise owing to their unusual axial length of 1.3 metres, and deep laminations which had to be used owing to the low frequency of the machines. The laminations have 270 open slots for the windings, which are held in place with fibre wedges. The inside diameter of the armature laminations is 4.1 metres.

The armature windings are designed as a three plane coil winding with two conductors per slot. Each conductor is divided into a great number of bars to reduce eddy current losses to a minimum. Each individual bar of the conductors is insulated from the next with impregnated cotton and mica strips, and each conductor is insulated by means of micanite insulation of special design; the two conductors in each slot are placed in a micanite tube by which they are insulated from iron. The micanite tube is filled with compound and pressed to the conductors during a heating process which unites

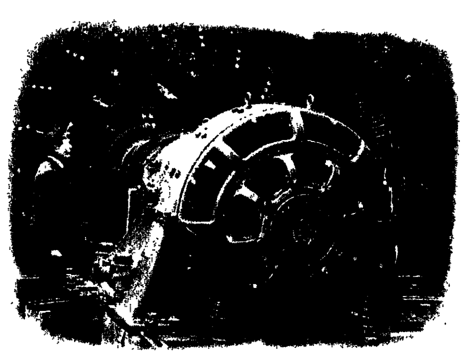


Fig. 225. Direct coupled exciter.

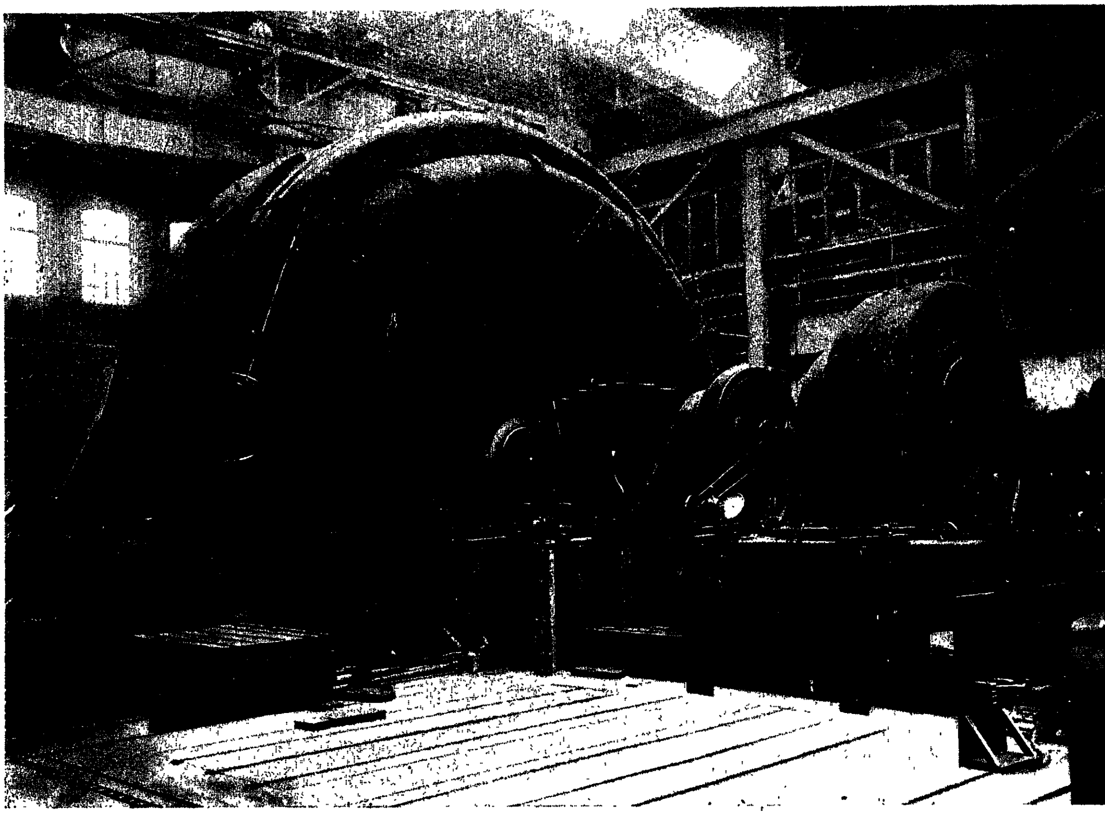


Fig. 226. Glomfjord generator on test.

the insulation on the conductors and the tube, thus forming a homogenous mass of insulation round the copper, avoiding any possibility of the production of ozone or nitric acid and also insuring an exceptionally good fit of the coils in the slots. Special protection is introduced to prevent corona or other disturbances which might arise due to the high voltage and which would be detrimental to the insulation. Outside the laminations the two conductors are separately insulated and held in rigid brackets. The insulation used for the free ends of the coils is so designed that it is impossible for the coils to be distorted due to short circuits or other outside troubles.

Special precautions have been taken with the insulation of the coils where they are attached to the brackets, the dielectric strength of the coils is as good here as in any other part of the machines.

Fig. 227. Roller arrangement in generator pit.

Owing to the length of the coils and the thickness of insulation employed there is always the danger of hot spots occurring, however carefully the design may have been calculated. In order to check the

temperature at various parts of the windings, thermo-couples were built in at different places in one of the generators, the windings are made of the best electrolytic copper. The leads from the generators, one from each phase and one from the neutral, are made of well insulated cables taken out through porcelain tubes in the end covers on the right hand side of the lower half of the stators, looking at the machine from the exciter end.

The rotors are of cast steel with the pole-rings and pole-pieces cast together; to facilitate transport, checking of the castings and machining, this casting is divided into several discs, shrunk on the centre spider, the outside discs being stepped and shrunk on the inside discs, and the whole held together by bolts through the pole pieces and also through the pole ring close to the centre (see Fig. 210). Special precautions have been taken to ensure efficient ventilation of the rotors and stators by arranging wide radial air ducts in the centres of the rotors. The pole-shoes are of cast steel secured to the pole-pieces by bolts. It is the usual practice to have laminated pole-shoes with open slot machines to reduce eddy currents, but in these machines investigations proved that with the large air-gap, the eddy currents need not be seriously taken into consideration, consequently the pole-shoes were made solid.

The field windings are of standard construction with copper strip wound on edge with 76.5 turns per pole designed for 220 volts excitation. The coils are insulated from iron by presspahn cylinders and washers and with paper and shellac between turns. On these machines, as on all Asea's big generators, provision has been made to guard against the possible danger of hot spots in the rotor windings. Apart from the large air ducts in the centre of the rotors, which ensure efficient cooling of parts which are most liable to become overheated in medium sized machines, the field coils are arranged with cooling fins which considerably increase the radiating surface of the windings. The coils are held in place by the pole-shoes but owing to the comparatively great axial length of the coils there was a danger of the coils being pulled out of shape by centrifugal force during the time the overspeed test was being carried out; to prevent this, brackets are placed between the coils in such a manner that it is impossible for them to be distorted. The leads from the field windings are of flat copper bars which are connected to the collector rings by being led outside the rotor ring, hub and shaft. The collector rings of cast iron are placed inside the generator bearing at the exciter end of the machines. Each ring has eight brushes mounted on a brush yoke attached to the bearing pedestal.

The spider arms, centre and rotor rings are made of cast steel. As the outside diameter of the ring is relatively small, compared with the axial length, the arms are not cast hollow as on other large machines but have a "cruciform" section (see Fig. 219). The

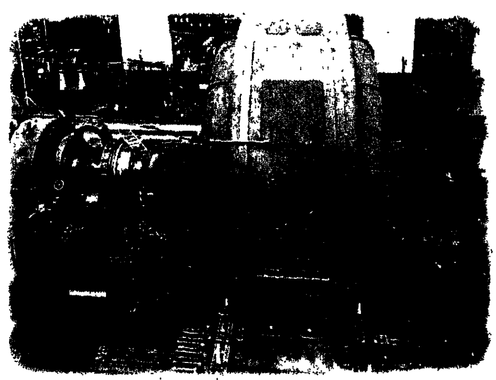


Fig. 228. Glomfjord generator in test room.

hub is secured to the shaft with two keys. The shafts have a length of 7.1 metres and are forged with solid flange couplings for connecting to the turbines at one end and extended at the other for the reception of the exciter armatures. On machines of this capacity, having heavy rotors and large power to transmit, the shafts have necessarily to be made stiff, consequently the shaft diameter is 0.66 metre inside the hub and the weight approximately 13 tons. To make absolutely sure that the forging of the shaft is perfect, the whole length was, counter-bored from end to end and the centre portion taken out in one piece, from which test pieces were made to check the steel specifications.

The shafts rest in low steel pedestals with babbit lined self adjusting bearings. Lubrication is accomplished by means of oil forced under the shaft under pressure at the time of starting, after which, oil rings come into play providing ample lubrication in conjunction with oil circulating system, oil being pumped from the basement through a filter and injected into the bearings on the top of the shaft. Direct water cooling is provided in the lower half of the bearings, and also by means of a cooling coil placed in the oil circulating system the oil is cooled before being again passed through the bearings. One of the bearing pedestals is insulated from the frame to prevent the circulation of parasitic currents.

The flywheel effect of the rotating masses is 8750000 kgms. The generators are mounted on separate bed plates for stators, bearings and exciters. The roller arrangement previously mentioned in the generator pit is mounted on a bed plate grouted into the foundation. All bed plates are held in place by foundation bolts.

The stator frames of the direct connected exciters are not supported on the bearing pedestals but are placed on separate baseplates with a certain amount of clearance between the main bearings, thereby allowing a jack to be placed under the shaft for lifting same between the bearing pedestal and exciter; the travelling crane is thus free to handle the bearing shells for inspection, etc.

The axial length of the machines is 7.4 metres from the turbine flange to outside the exciter, 8.4 metres across the stator feet. The highest point on stators is 4.075 metres above floor level, the centre line of the machines is 0.75 metre above and the bottom of the pit 3.4 metres below floor level.

The weight of a complete machine is about 225 tons, 110 tons being in the stator, 83 tons in the rotor and the remaining 32 tons in bearings and bedplate. The exciters weigh about 7 tons each.

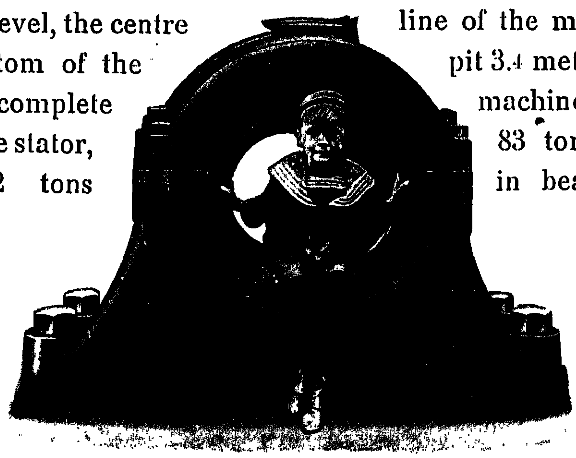


Fig. 229. Large bearing of Glomfjord generator.

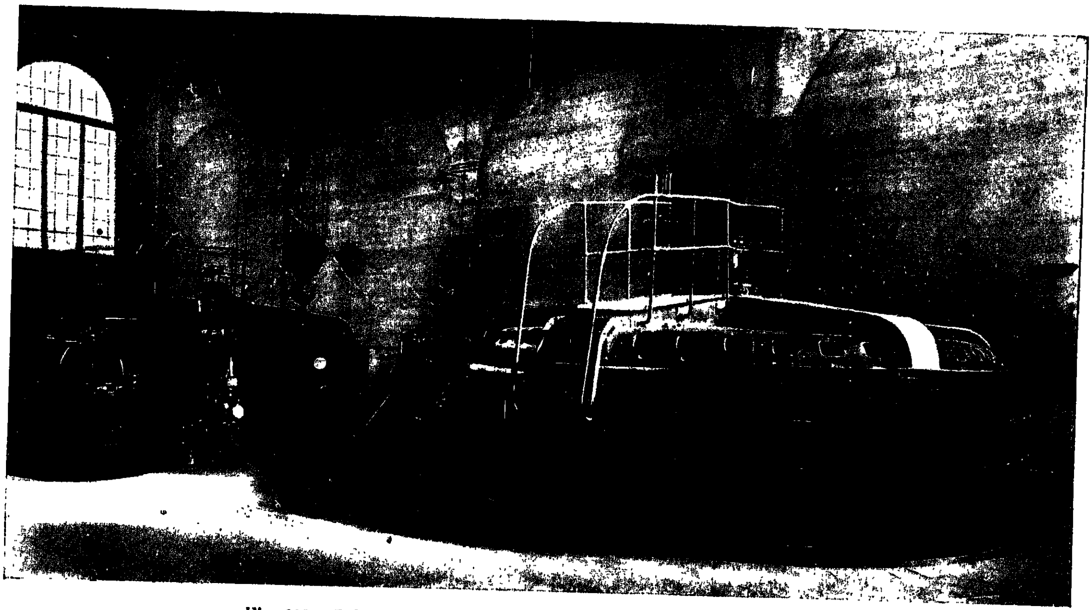


Fig. 230. Calgary Power Co's Power Station at Kananaskis Falls.

CALGARY POWER Co., Ltd., CANADA

AS previously mentioned, Asea has supplied a considerable number of generators for Canadian power stations. These generators, mostly of the older type are from to-day's point of view rather small machines as is only natural when taking shop, transport, and erection facilities into consideration at the time of their construction. The capacity of generator units used in Canadian power stations has not increased as rapidly as in those of other countries, as for example the Swedish State power station at Trollhättan and the Rjukan installations in Norway. The primary reason for this is the nature of the Canadian rivers with their large bodies of water and comparatively low heads, for which the most suitable turbine is the vertical slow speed low powered type. The majority of the larger machines supplied by Asea to Canada are consequently built for speed from 163 to 90 r. p. m. and for capacities of about 1000 KVA per unit.

During the past few years some exceptions to this rule have taken place and Asea engineers have been estimating on some of the largest machines in the world, whilst several fairly large generators have already been built for Canada; for example those supplied to Messrs. E. B. Eddy Co., of 3750 KVA each, the generators for Healey's falls of the same capacity and the two generators for the Calgary Power Co's installation of which a short description follows.

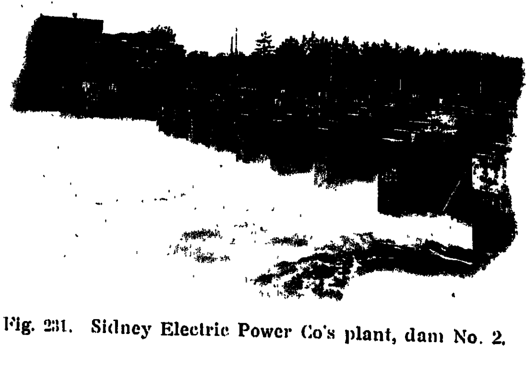


Fig. 231. Sidney Electric Power Co's plant, dam No. 2.

Fig. 282. Four Asea generators in the Sidney Electric Power Co's Stations each of 940 KVA at 120 r. p. m., 60 cycles, and 6600 volts.

These two 3-phase generators have now been in operation since 1913 and are erected in the power station at Kananaskis falls, about 3 kms from Horseshoe falls on the Bow river, 80 kms west of the city of Calgary, Alberta. Besides the two generators mentioned Asea also supplied this station with an exciter, having a capacity sufficiently great to supply the field current for both the generator units, direct coupled to a vertical turbine. Also a motor generator set as a standby for the turbine driven exciter. The power station, which was built in the short time of twelve months, is only equipped with these two machines, and is tied in with an older station at Horseshoe falls by two transmission lines; at the latter station the voltage is stepped up to 55000 volts for transmission to Calgary. A small portion of the output is delivered to a cement work situated in the neighbourhood at the generator voltage. Power used for station requirements and the surrounding property is stepped down to 2200 volts. The generators are designed for a continuous output of 4250 KVA, 12000 volts, 163 r. p. m., 60 cycles at 80 % power factor. They have stationary armatures with rotating fields on vertical shafts with solid flanges for direct coupling to the turbines. The stator frames are of cast iron erected on cast iron bottom rings which also carry the lower bearing spiders; the upper bearing spiders or cross arms are supported

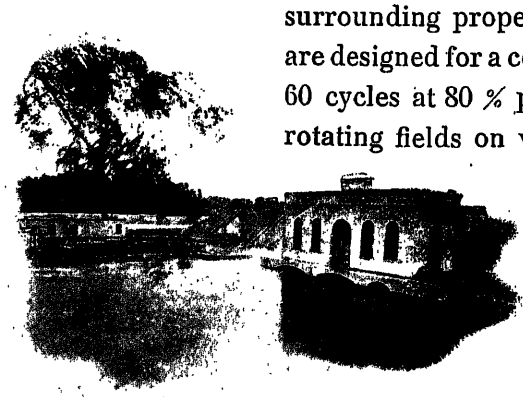


Fig. 283. One of the Sidney Electric Power Co's Stations, Canada.

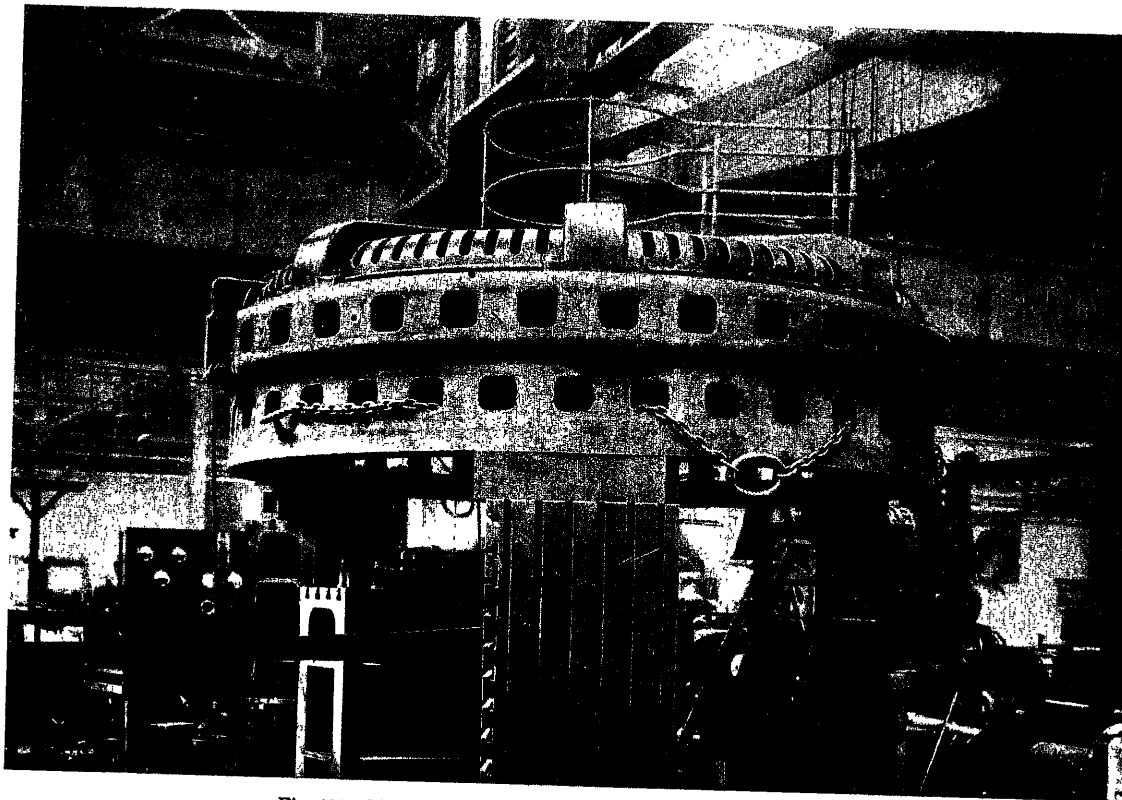


Fig. 234. Modern vertical three-phase generator during test.

on the upper edge of the stator rings. The openings between these arms are partly enclosed in order to prevent dirt and dust from entering the machines. The spiders also carry the guide bearings which keep the shafts in their vertical position and the airgap even all round; the thrust bearings were supplied by the turbine makers and carry the whole weight of the rotors and turbine runners.

The armature laminations are secured to the stator frames in the usual manner and the frames split to facilitate transport, even under these conditions difficulties were encountered, as no tackle was available at the harbour or on the steamer sufficiently heavy to handle these pieces. The stator diameter at the air gap is 4.6 metres and the laminations have 264 semi-closed slots to receive the windings. The windings are of the two plane coil type heavily insulated on account of the high voltage. This insulation consists of double impregnated cotton covering on the bars with presspahn between turns and a 5 m/m seamles micanite tube outside the complete coil containing six bars; the micanite tubes extend for a short distance over the free ends of the coils. The insulation on the free ends of the coils is made of flexible insulating material such as empire cloth and tape which is applied with

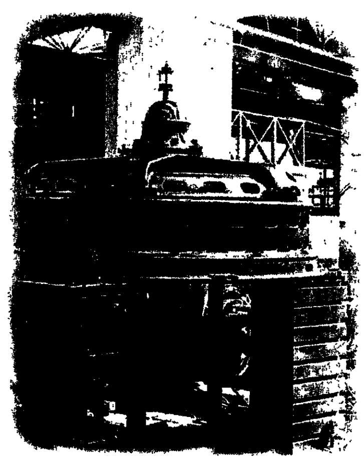


Fig. 235. Small vertical three-phase generator.

insulating varnish and is of ample thickness to ensure against the possibility of breakdown. On account of the high generator voltage (12000 volts between phases) very rigid specifications were drawn up. During the acceptance test the machines were subjected to 30000 volts A. C. for one minute between phases and also to ground. The free ends of the coils are well braced to prevent distortion or damage due to short circuits or heavy surges.

The rotors are made with a solid pole ring but with detachable pole-pieces to allow for transport. These pole-pieces are also of cast steel held to the ring by bolting from the inside. If the standard construction had been adopted for these generators a cast iron ring could have been used, but as the purchaser specified an overspeed test of 100 %, it was decided to make the ring of cast steel. The pole-shoes are solid bolted to the pole-pieces. The field coils are wound with copper strip on edge which is held in place by the pole-shoes. The flywheel effect of the rotating masses is 1250000 kgms.

The field current is taken from the collector rings on top of the generators through cables which are carried part of the way inside the shaft. A platform is arranged on top of the generators to enable the operator to inspect the rings whilst the machines are running and a stairway and gangway is provided over one of the bearing spider arms on one side of the machines.

These generators which are some of the largest that Asea have supplied to Canada, occupy a floor space of 6.3 metres outside the foundation ring. The top of the railings around the collector ring inspection platform is 3.03 metres above and the lower end of the shaft 1.53 metres below the floor level.

The weight of each complete machine is about 71 tons, of this 26.2 tons are in the stator, 25.5 tons in the rotor and shaft, the bottom ring and bearing spider account for 14.6 tons and the remainder is in the bearings and other details.

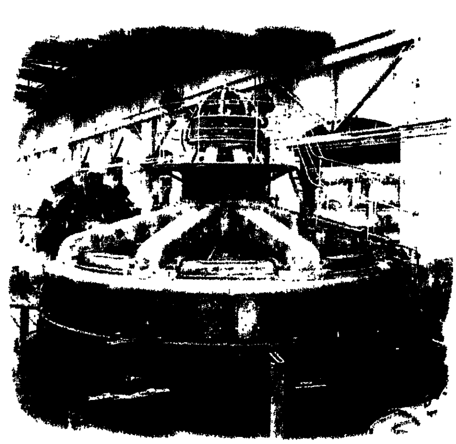


Fig. 236. 4800 KVA totally enclosed three-phase vertical generator with direct coupled exciter and supporting bearing erected for test.

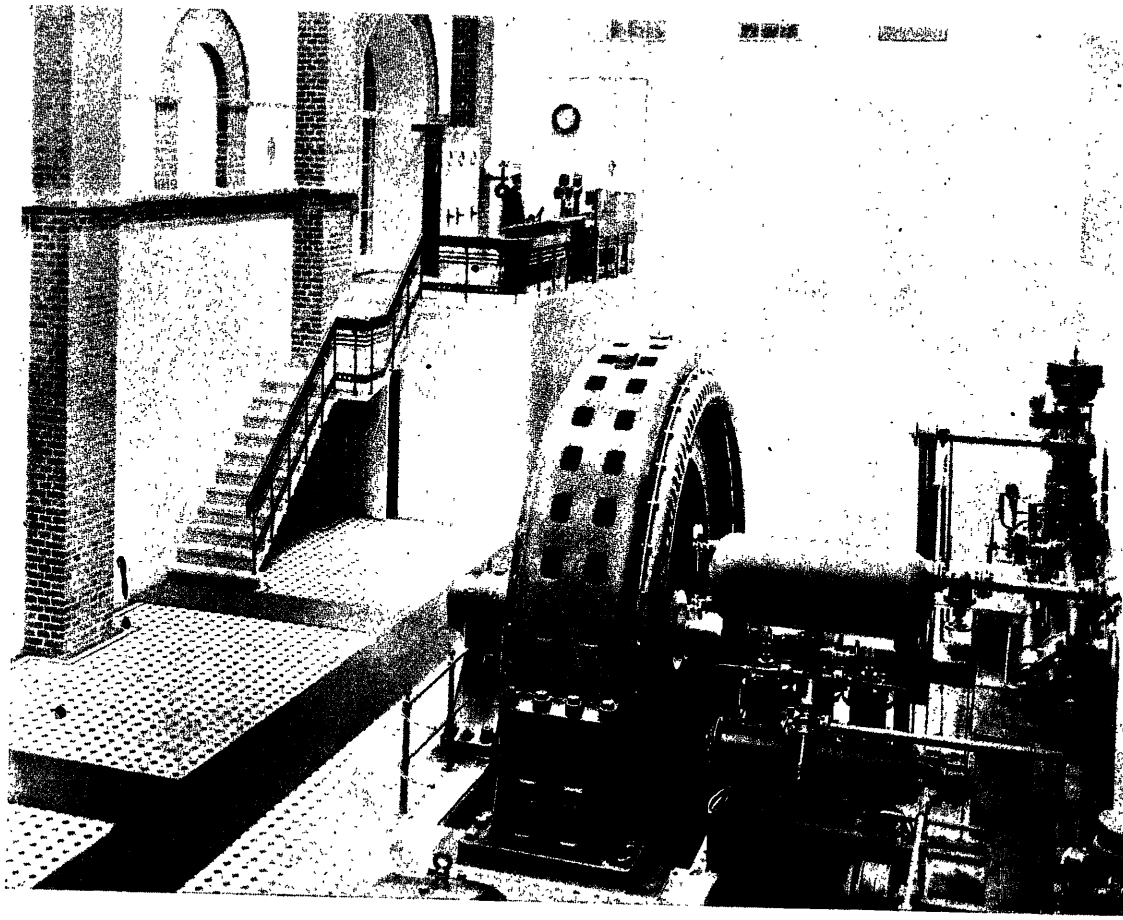


Fig. 237. Interior of Nokia power station.

NOKIA COMPANY, FINLAND.

In the chapter relating the growth of Asea's generator production, the fact was mentioned that Asea had built up a market for its generators in Finland. The machines supplied to this country, with a few exceptions, are of relatively small sizes although perhaps at the time of their construction they were considered large. If, however, compared with machines of Asea's more recent manufacture, those for instance for the Norwegian government, Norsk Hydro-elektrisk, Kvælstof A/S etc., they must now be classified amongst the smaller types. Finland is one of the countries best provided with water falls in the world and will undoubtedly, now that the war is over

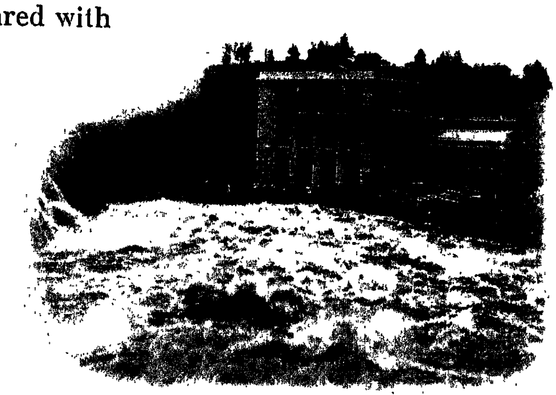


Fig. 238. Nokia power station.

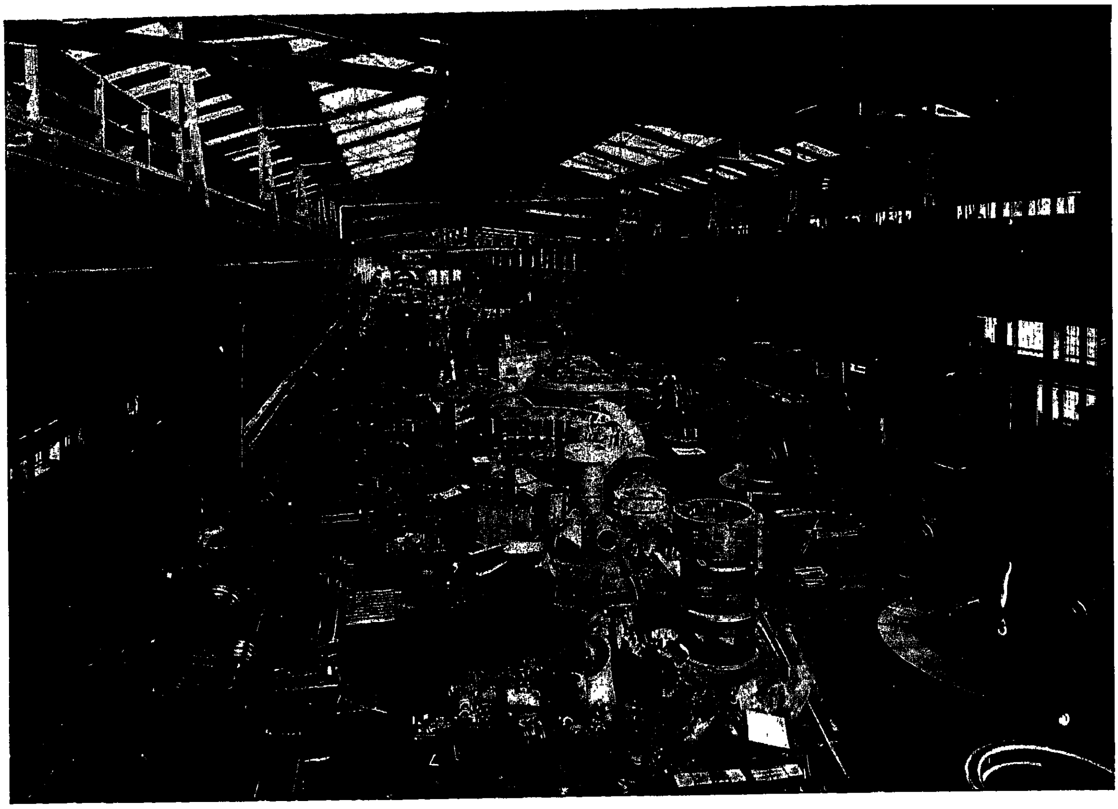


Fig. 239. One of Asea's shops for large machines.

and conditions are getting back to their normal state, develop some of the big hydro-electric power projects which Asea has been assisting with by estimates and technical advice. Some of the large generators estimated for this country will compare very favorably with other large machines which have been mentioned in the preceding pages. The largest generator that has so far been supplied to Finland is a three-phase generator for Nokia A/B delivered in 1912.

The above mentioned company owns a power station at Nokia 15 kms from Tammerfors, the electrical equipment of which consists of the generator already referred to and also one of Asea's D. C. generators. Asea also supplied the necessary switch-gear and power line for transmitting part of the energy to Tammerfors at 30000 volts. The majority of the power generated is absorbed in a neighbouring paper mill at Nokia, where it is used for raising steam in an electric boiler and for various motor drives.

The 3-phase generator is constructed on the modern "G" type specifications with a continuous output of 3600 KVA, 5250 volts, 167 r. p. m., 50 cycles, at 80 % power factor. The machine is of the open type with

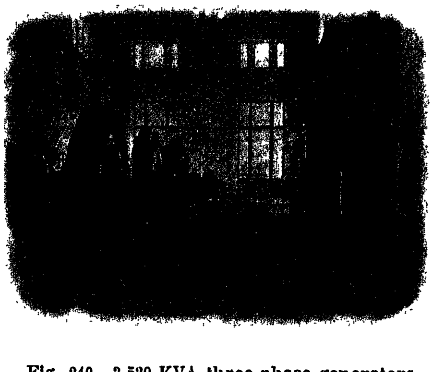


Fig. 240. 3-530 KVA three-phase generators, 5500 volts, 125 r. p. m., 50 cycles in the Stockfors Co's power station, Finland.

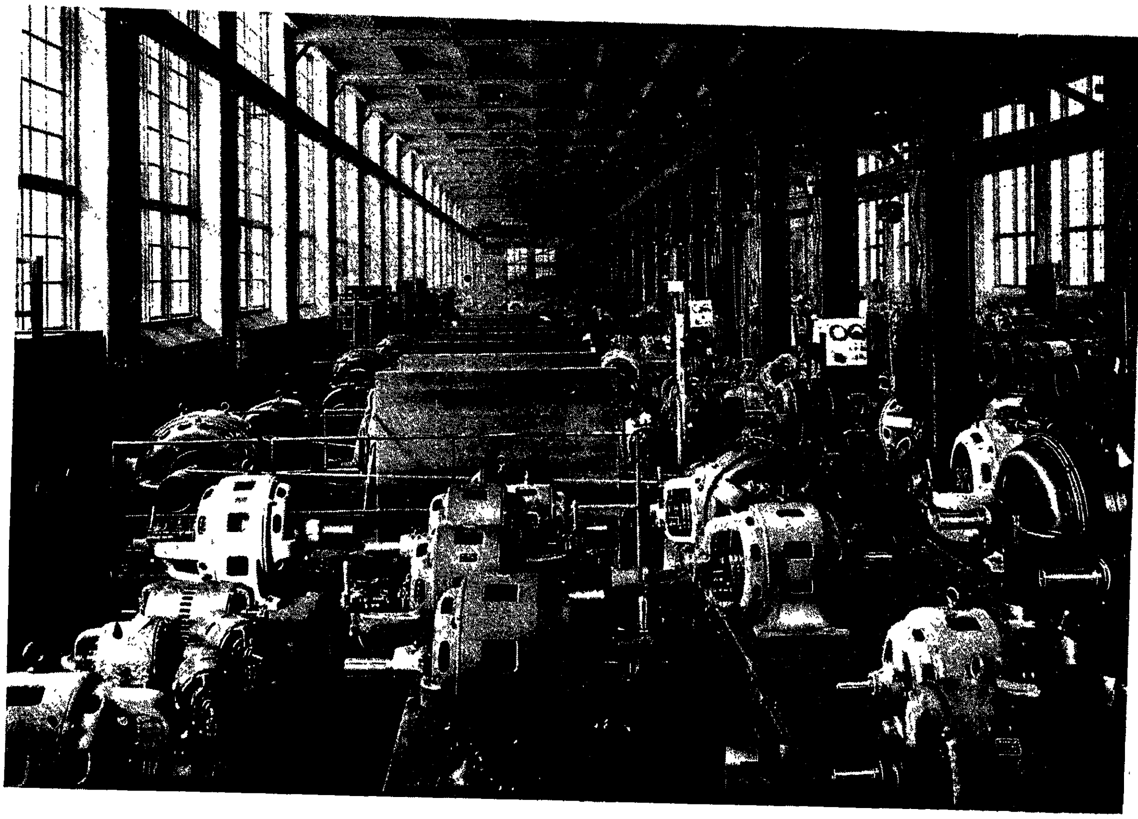


Fig. 241. One of Asea's test rooms for small machines.

stationary armature, rotating field on horizontal shaft and solid flange coupling for direct connection to the water turbine. The stator is built according to standard design and is made of cast iron split horizontally, the halves being bolted together. The laminations and windings are perfectly standard; the former are made of best Swedish iron, dovetailed into the frame and divided into several sections by air ducts. Each section has an axial length of about 60 m/m, which is further divided by presspahn insulation and each individual sheet is insulated with paper. The winding is of the two-plane coil type distributed in 216 semi-closed slots and insulated from iron by seamless micanite tubes. These tubes have a thickness of 3.5 m/m and the coils consist of four bars which are insulated from each other with presspahn and double cotton insulation. The free ends of the coils are insulated with impregnated tape and protected by cast iron end shields. The rotor is not built according to standard construction owing to the conditions enumerated below. Firstly the peripheral speed is rather high, in addition to which the specification called for a rotor heavy enough to take the place of a flywheel required for the turbine regulation, consequently steel had to be

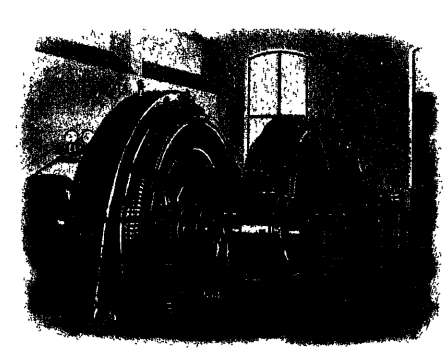


Fig. 242. 2 Asea three-phase generators, 510 KVA, 10000 volts, 187 r. p. m., 50 cycles at the Värtsilä Works power station in Finland.

used; lastly the transport facilities were such that the smallest possible pieces were necessary. To make the rotor perfectly safe during the overspeed test, the rotor ring is also made of cast steel and in one casting with some of the pole-pieces. This ring is shrunk on to the cast iron flywheel ring which is cast in one piece with the hub and arms of the rotor centre. In order to make transportation possible, ten of the pole-pieces are detachable, five on each side, and are secured to the pole-ring by bolts. The outside diameter of the rotor is in this way reduced to such dimensions as to allow for transportation on standard freight trains in Sweden. In Finland however, it had to be transported on special trucks.

The pole-shoes are of wrought iron held in place by bolts. The field windings consist of 72 turns of copper strip on edge per pole insulated in the usual manner and held in place by the pole-shoes. The field leads are secured to one of the arms then over the hub and along the shaft to the collector rings which are placed inside the bearing.

The flywheel effect of the rotor is 930000 kgms. The generator measures axially 3.68 metres from the turbine flange to outside the bearing and 5.64 metres across the stator feet; from floor level to highest point on stator is 3.45 metres. The centre line of machine is 1 metre above and the bottom of the pit 1.56 metres below floor level.

The weight of the complete machine is about 57 tons, of this the stator weighs 19 tons, rotor and shaft 29 tons, the remainder being in the bearings and bedplate.

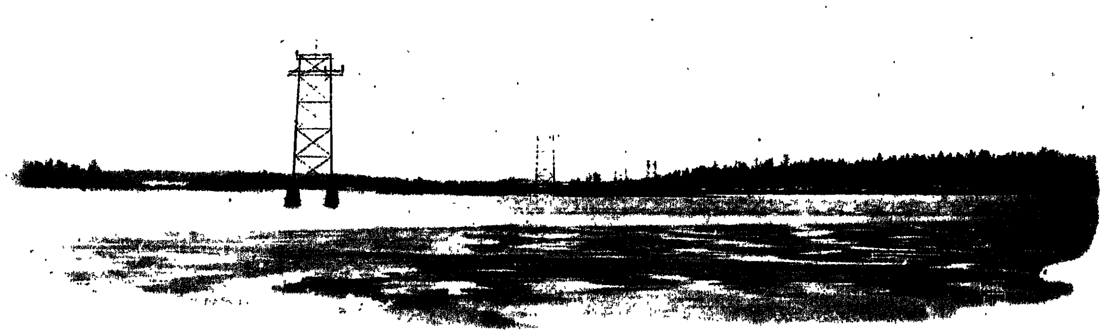


Fig. 243. Nokia-Tammerfors transmission line crossing Pyhäjärvi.

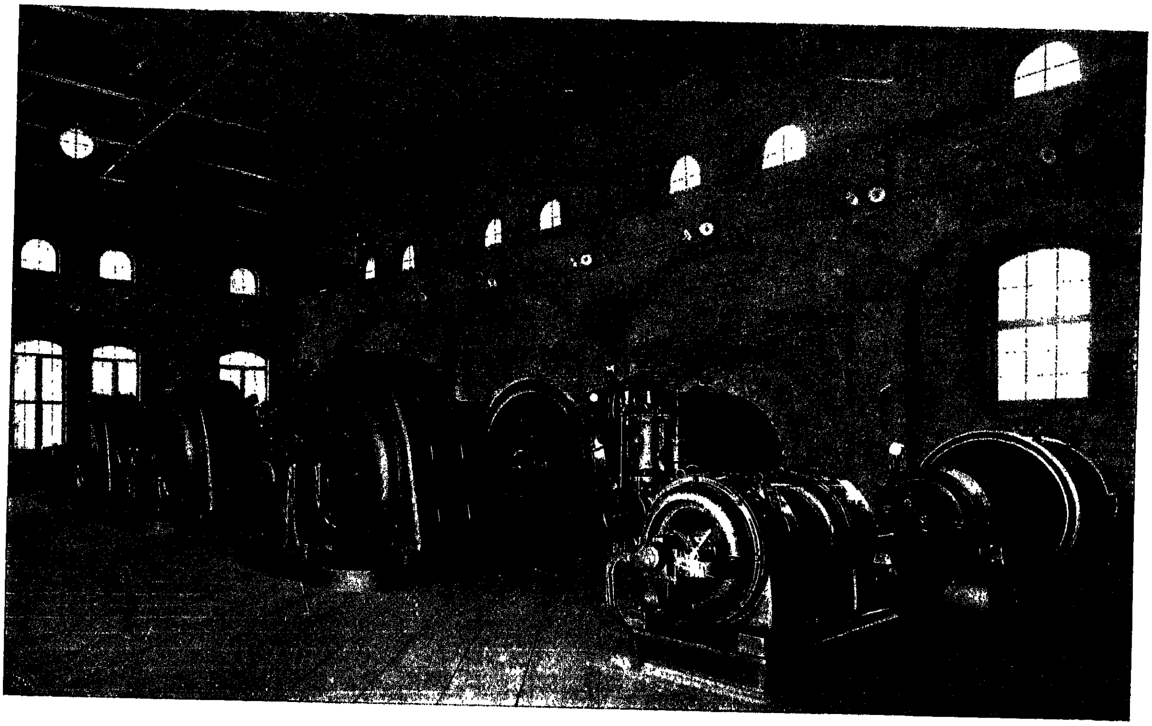


Fig. 244. Interior of Sagami I power station.

SAGAMI HYDRO ELECTRIC POWER Co., JAPAN.

FOR some considerable time Asea's only foreign market, outside of Europe, was in Canada and Asea not only supplied a great number of smaller types of machines and apparatus but generators of fairly large size to that country before the export trade to other foreign countries (outside our own continent) started to assume any cousiderable proportions. These conditions had however commenced to change quite noticably before the beginning of the war and Asea's products had started to find their way to the majority of the remaining parts of the hemisphere. At the present time Asea's trade mark is undoubtedly well known in all parts of the world where a powerful domestic industry or high import duty does not prevent them obtaining a foothold.

Among the various countries in which Asea had built up an extensive market before the war was Japan, although after the war started this had to be broken off. During

Fig. 245. Fuji-yama.

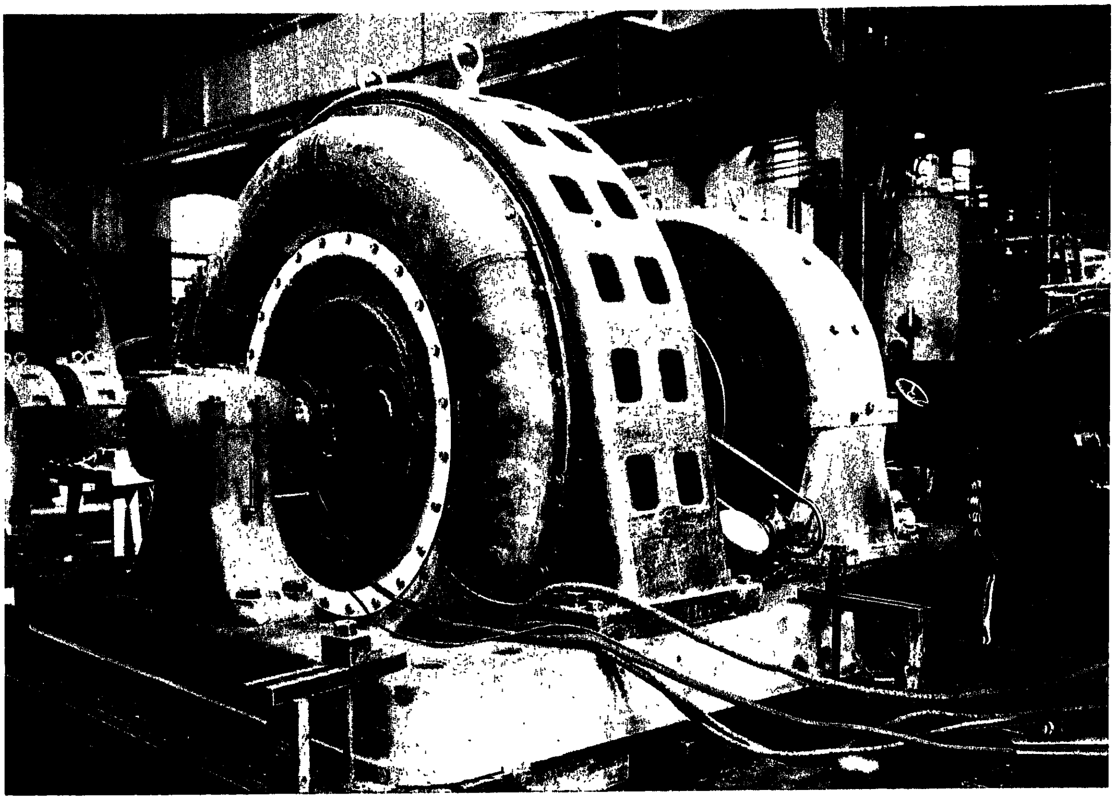
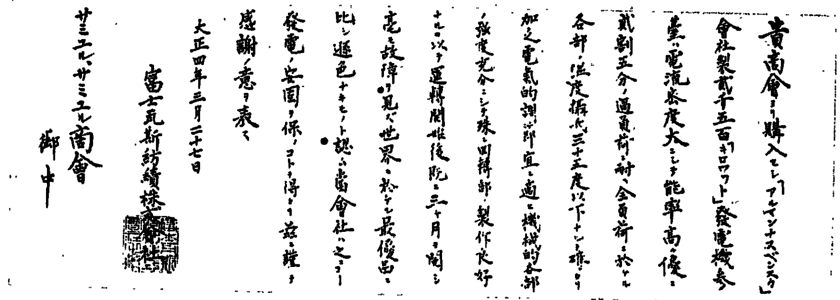


Fig. 246. Semi-enclosed three-phase generator for Sagami during works test.

1912 to 1915 Asea exported to Japan not only a large number of small machines and apparatus but also some generators of moderately large capacities. These generators were built for the Sagami hydro-electric power company for the two power stations Sagami I and Sagami II situated close to the railway station at Yamakita, which is about two hours journey by rail south of Tokio. The two power stations are located at the lower end of the Sagawa river, at which point it arrives from its source on the East side of the Fuji-yama (the holy mountain of Japan 1000 metres above sea level) without any large waterfall but by numerous rapids. The water volume is estimated at about 22 cubic metres per second.

Sagami I station is situated further up the river than Sagami II. In this former station a head of 40 metres is available by the construction of a tunnel 2 kms long through the mountain parallel with the river. Sagami II station is located about 3 kms down the river from Sagami I and at this station a head of 25 metres is available. Each station is equipped with 3 three-phase generators and one common exciter, all direct coupled to their own water

Fig. 247. Sagami I power station.



Translation of the original.

We have purchased three electric generators each of 2500 KVA from your Firm (The Swedish General Electric). Their electrical output is large and capacity high. They easily give a voltage 25 % higher than the normal, and under full load a temperature rise not exceeding 35° C. for all parts is ensured. In addition each part of the machines has worked excellently and the maintained good quality of the electrical parts has been very satisfactory. The rotating parts are especially worthy of mention and after three months service no fault of any kind has occurred. We freely admit that these generators can well be compared with the foremost in the world and that they can always be depended upon for the maintainance of an uninterrupted supply of electric energy, a fact which this Company has pleasure in attesting to.

Samuel Samuel & Co. Ltd.

Fuji Gasu Boseki Kabushiki Kaisha

27th. March, year 4 in the Taisho period.

Fig. 248. Acceptance of generators Sagami I.

turbines built by the Karlstad Co.; also one motor generator as spare for the exciters.

The three-phase generators for Sagami I are each designed for a continuous full load of 2500 KVA, 500 r. p. m., 6600 volts, 50 cycles, at 86 % power factor; the machines supplied to Sagami II are only rated for 1500 KVA but otherwise are similar. The machines are, with a few exceptions, built on Asea's standard lines with stationary armatures and rotating fields on horizontal shafts. The stator frames are of cast iron and not split, the stator laminations are of the best Swedish iron divided up into sections by radial air ducts and insulated from each other by paper. The inside periphery of the armature has 144 semi-closed slots for the reception of the windings, which are of the two plane type wound with best electrolytic copper and insulated from the stampings by a seamless micanite tube 3.5 m/m thick. The individual conductors in each tube are insulated from each other by presspahn strips and each bar has a double cotton imregnated insulation. The free ends of the coils are insulated in the standard manner with tape and varnish; the end plates, of cast iron without openings, are radially deep enough to cover not only the stator

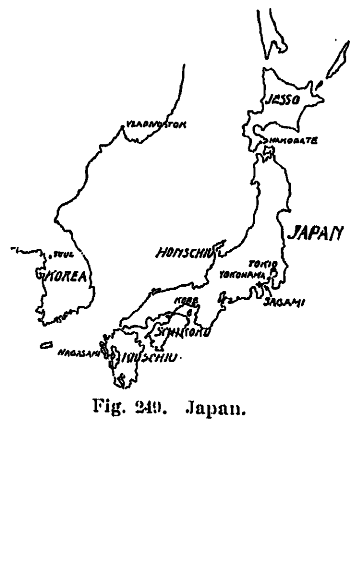


Fig. 249. Japan.

windings but also the field coils and rotor ring, thereby making the machines semi-enclosed. This construction was decided on in order to eliminate as much as possible the noise from the machines, due to their high speed.

The rotors are made with pole-pieces and pole-ring in one steel casting shrunk on to a cast iron centre. As separate flywheels were furnished for the turbines there was no necessity to arrange for any extra weight in the rotors so that only enough material is put into them to insure a good magnetic circuit and ample mechanical strength. The field windings are of copper strip on edge, according to usual practice in large machines and are insulated between turns with paper and shellac and from iron with presspahn cylinders and washers. The field coils are held in place by the pole-shoes which are bolted to the pole-pieces. The shaft, made from Swedish steel, is furnished with a belt pulley forged in one piece with the shaft and placed inside the coupling flange near the flywheel; this pulley is used for driving a govenor for regulating the speed of the turbine. The shaft is supported in two horizontal bearings, fitted with oil ring lubrication and a water cooling system, to reduce the temperature to a minimum. The bearings are designed large enough to run satisfactorily should the cooling water be shut off for any reason.

To allow for inspection and possible repairs the stators are so arranged that they can be moved parallel to the shaft on the bed plates, which are cast in one piece.

The flywheel effect of the rotating masses on the larger machines is 500000 kgms and on the smaller ones 310000 kgms.

The larger machines measure 3.7 metres axially, 3.34 metres across the stator feet. Highest point on stator frame is 2.53 metres and centre of shaft 1 metre above floor level. These dimensions also apply to the smaller machines except the diameter, which is 3.12 metres.

The weight of each of the large generators is 25800 kgs whilst that of the smaller ones is about 19500 kgs.

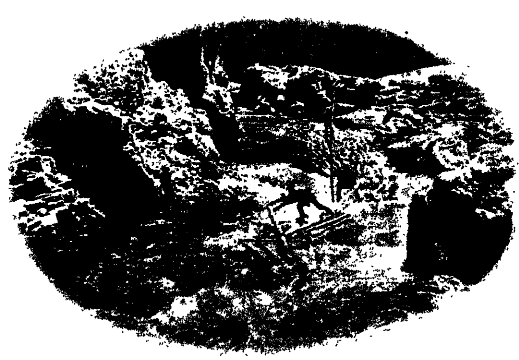


Fig. 250. Japanese river scene.

CONSTRUCTION OF ASEA'S LARGE GENERATORS

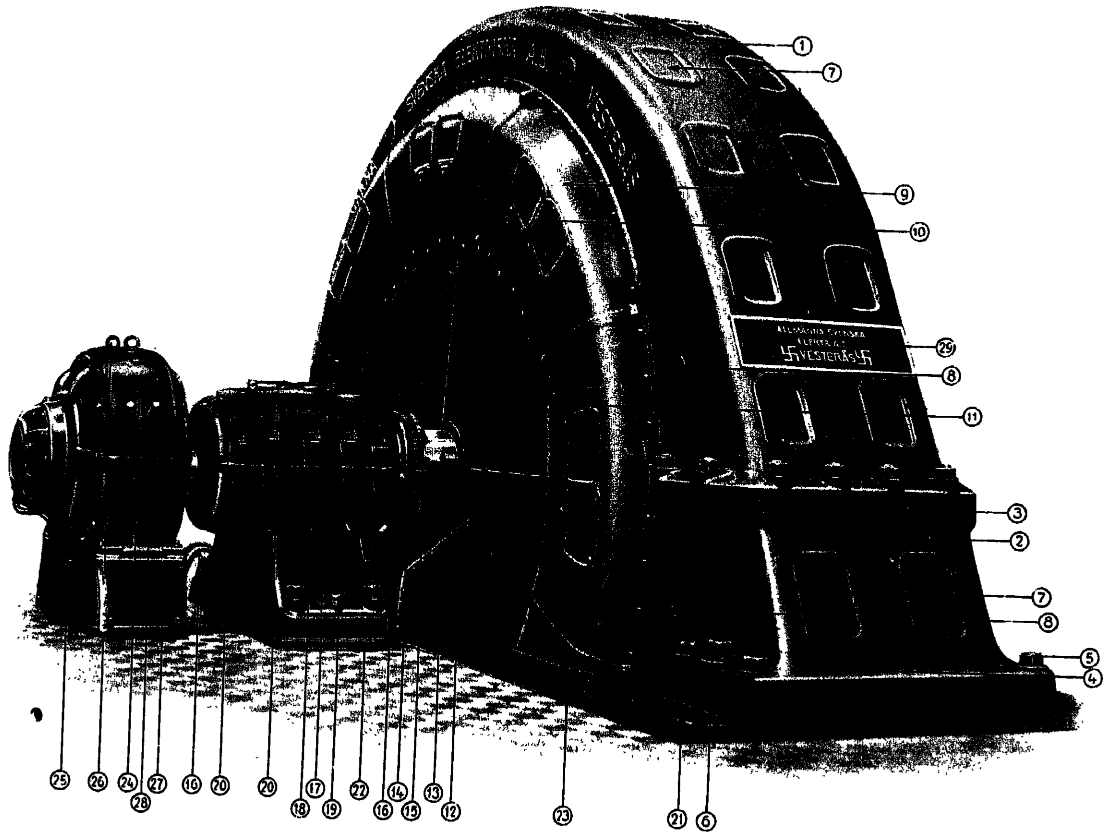


Fig. 251. Modern totally enclosed alternator with direct coupled exciter.

1. Upper half of stator frame. 2. Lower half of stator frame. 3. Dividing line of upper and lower halves of stator frame. 4. Stator feet. 5. Holding down bolts. 6 Adjusting screw. 7. Cover plates over openings in stator frame. 8. Holes for attaching lifting tackle. 9. Solid end shields. 10. Inspection covers in end shields. 11. Inner cover plates. 12. Air intake. 13. Shaft. 14. Slip rings. 15. Brush carrier and brushes. 16. Cables between exciter and slip rings. 17. Bearing cap. 18. Bearing pedestal. 19. Adjusting screw. 20. Oil hole cover. 21. Stator soleplate grouted into foundation and secured with foundation bolts. 22. Bearing soleplate grouted into foundation and secured with foundation bolts. 23. Cover plates over generator pit. 24. Exciter yoke. 25. Brush carrier. 26. Eye bolts. 27. Exciter baseplate. 28. Bolts holding pole-pieces. 29. Name plate.

THE COMPONENT PARTS OF ASEA'S THREE-PHASE GENERATOR.

THE Alternating Current Generator is a machine which converts mechanical into electrical energy in the form of alternating current. It consists of three principal parts: the stationary portion called the "stator", the rotating part termed the "rotor", and the bearings which support the shaft to which the rotor is attached.

The stator comprises the main frame for housing the laminations and winding, accessory parts of the stator are coverplates (9), eyebolts, foundation bolts (5), and dowel pins (6), (see illustration Fig. 251).

The stator frame (1 and 2 Fig. 251) is of cast iron, and either in one piece as indicated in Fig. 256, or split as shown in Figs. 251 and 255, in which case the two parts are rigidly bolted together. For mounting on the bedplate the stator is provided with massive feet, (4 Fig. 251) and is constructed with openings for ventilation as indicated in Fig. 255, or

alternatively with cover plates (7) as Fig. 251. The axial faces are always made without openings to allow for bolting on of end-shields (9 Fig. 251). On the inside of the stator frame the laminations are packed, pressed, and keyed or bolted (see items 1 Fig. 252 and 4 Fig. 254). The laminations are of 0.5 m/m selected sheet iron but these before being placed in the stator are stamped to the requisite shape in a machine which forms the slots for the windings (3 Fig. 252), and the keyways required to hold the laminations in place. The laminations are insulated from one another by paper about 0.03 thick, pasted on one side of the sheet iron before punching. To hold the laminations together they are pressed between substantial flanges secured to the frame and provided with projections corresponding to the stator teeth (7 Fig. 254). The laminations are diveded into sections by radial cooling ducts or channels (4 Fig. 252, 6 Fig. 254), and on the inner face are provided with a number of slots — the winding slots — of open (3 Fig. 252) or partly closed form (8 Fig. 254) in which the windings (5, 6, or 7 Fig. 252, 9 or 10 Fig. 254) are inserted. The conductors are of high grade electrolytic copper wire or bars insulated from one another by cotton or paper applied by special covering machines and when necessary impregnated with varnish; for high voltage machines moulded micanite is used. The parts of the coils projecting beyond the laminations are connected together in various ways, depending upon the number of conductors, their size, and whether a bar, drum, or coil winding is decided upon (9 or 10 Fig. 254). The windings are insulated from the laminations with high grade materials depending upon the voltage of the machine. For low voltages it is customary to use pressphan or specially prepared insulating paper, and for higher voltages mica. Beyond the laminations the coils are insulated with tape and empire cloth. The ends of

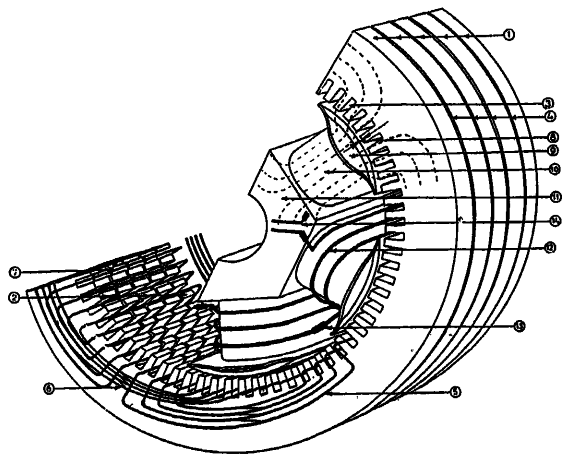


Fig. 252. Diagram of three-phase generator.

1. Armature laminations divided in 5 sections by ventilating ducts. 2. Stator teeth. 3. Slots, open type. 4. Ventilating ducts. 5. Coil belonging to first group windings, bent outwards. 6. Coil belonging to second group of straight plane winding. *Note:* the winding shown is part of a three-phase two plane coil winding divided into four slots per pole per phase. Each group consists of four coils; the connections between coils are shown (see item 6) but connections between the coil groups are not shown. 7. Slot with coil. 8. Air gap. 9. Pole-shoe. 10. Pole-piece. 11. Rotor hub. 12. Field coil shown $2^1/_2$ turns per pole. 13. Connection between field-coils. 14. Field windings.

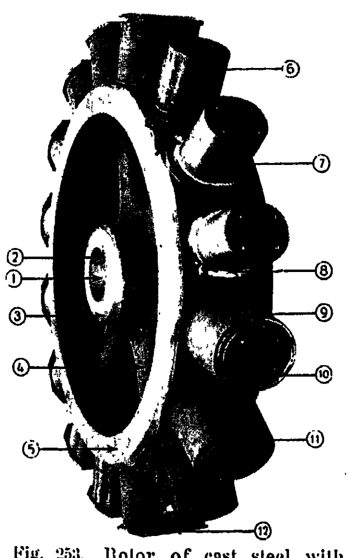


Fig. 253. Rotor of cast steel with field coils for modern three-phase generator.

1. Bore of shaft. 2. Keyway. 3. Hub. 4 Arms. 5. Magnet ring—rotor ring. 6. Pole piece without winding. 7. Insulating sleeve. 8. Insulating washer. 9. Wound field coil. 10. Connection between field coils. 11. Holes drilled and tapped for securing pole-shoes. 12. Pole-shoe.

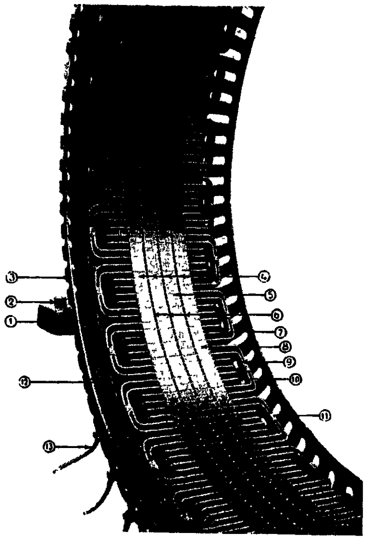


Fig. 254. Part of stator for modern three-phase generator with two-plane coil windings.

1. Stator foot. 2. Dowel pin. 3. End shields. 4. Stator laminations divided into four sections by air ducts. 5. Stator teeth. 6. Radial cooling ducts. 7. Finger of clamping ring. 8. Semi-closed slot. 9. Coil group consisting of two coils of straight winding. 10. Coil of outer plane. 11. Binding cord. 12. Connection between coil groups. 13. Leads.

the windings are brought to terminals (13 Fig. 254) to which are attached the main cables leading to the switchboard.

Between the fixed portion (the stator) and the moving part (the rotor) is an air space technically called the "air gap" (8 Fig. 252) whose dimensions are determined by magnetic and mechanical considerations. On small machines this air gap may be only a few millimetres but on large generators will be as much as 20 to 30 millimeters or more.

The rotor consists of the magnet ring, poles, pole shoes, magnetising coils and the spider on which these parts are supported; the hub and shaft, the latter having the collector rings mounted upon it.

The magnet ring and pole pieces are either made in one piece of Siemens-Martin Steel (see Figs. 252 and 253), or alternatively of cast iron or cast steel with forged pole pieces bolted thereto (see Fig. 8). The pole shoes (9 Fig. 252, 12 Fig. 253) are in some cases laminated, that is to say the part of the shoes adjacent to the air gap is made from sheet iron keyed to the solid part of the shoe. In other cases the shoes are solid throughout — usually forgings — bolted to the pole cores. (11 Fig. 253). The rotor winding (12 Fig. 252) is made from the same high grade copper as the stator winding taking the form of coils placed on the

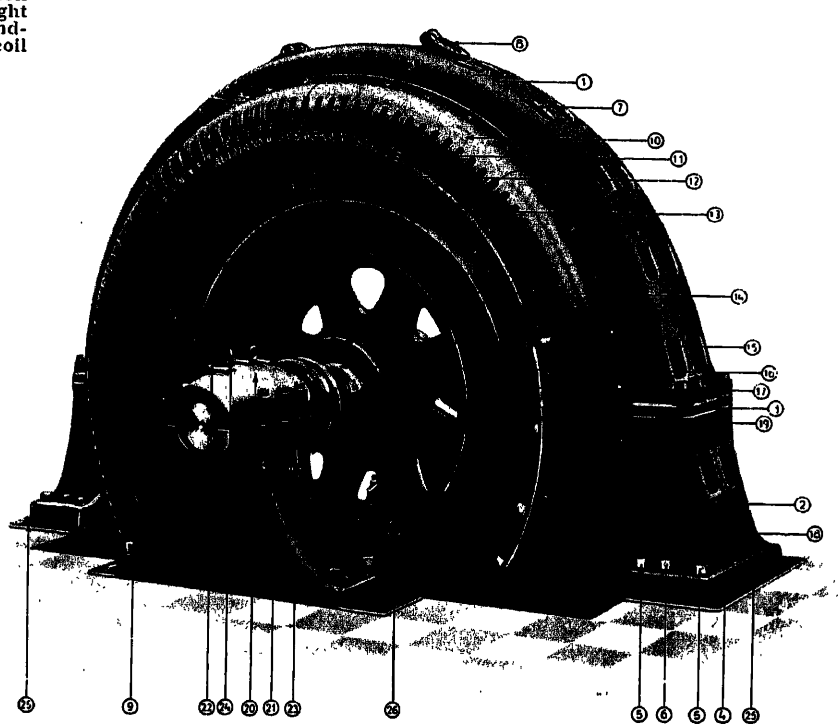


Fig. 255. Modern open type three-phase generator.

1. Upper half of stator. 2. Lower half of stator. 3. Horizontal split in stator frame. 4. Stator foot. 5. Holding down bolts. 6. Dowel pin. 7. Ventilating openings in periphery of stator frame. 8. Lifting shackles. 9. Stator winding. 10. End shields. 11 Pole-shoe 12. Field coil (part of rotor winding) 13. Rotor ring. 14. Arm. 15. Hub. 16. Shaft. 17. Key. 18. Field leads. 19. Collector rings. 20. Bearing cap. 21. Bearing pedestal. 22. Oil hole cover. 23 Oil gauge with drain cock. 24. Eye bolt. 25. Stator soleplate grouted into foundation and held in place by foundation bolts. 26. Bearing soleplate grouted into foundation and held by foundation bolts.

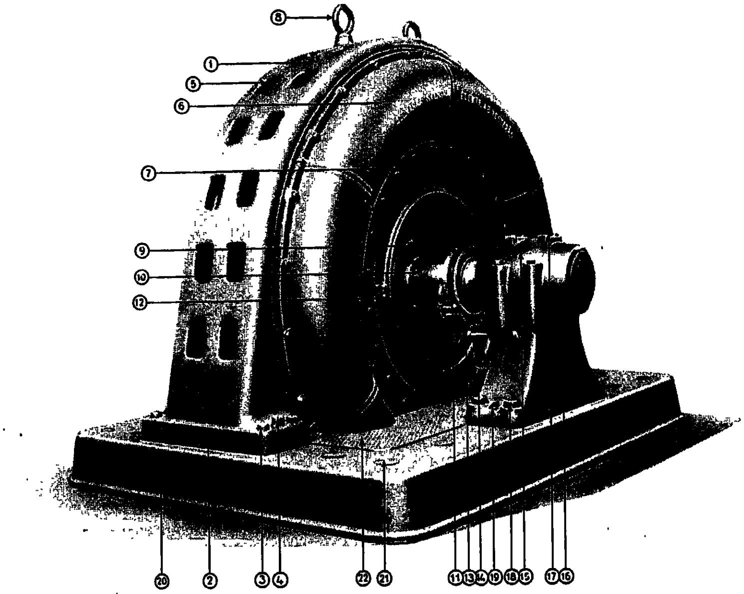


Fig. 256. Modern semi-enclosed three-phase generator.

1. Stator frame. 2. Stator foot. 3. Holding down bolt. 4. Adjusting screw. 5. Openings in stator frame for ventilation. 6. Solid end shields. 7. Inner cover plates. 8. Eye bolts. 9. Hub. 10. Shaft. 11. Collector rings. 12. Brush holder and brush. 13. Brush carrier. 14. Field cables. 15. Bearing cap. 16. Bearing pedestal. 17. Oil hole cover. 18. Holding down bolt. 19. Dowel pin. 20. Box bedplate. 21. Cover over foundation bolt hole. 22. Generator pit cover.

pole pieces and held in place by the pole shoes. These coils are either of copper wire suitably cotton covered, wound on a bobbin (9 Fig. 253) or of strip on edge in one layer; in the latter case they are insulated between turns by specially prepared and impregnated fibrous insulating material. In both cases the coils are insulated from the iron with cylinders and end-cheeks of selected insulation whose properties are such that it is both mechanically and electrically sound (7 and 8 Fig. 253). These coils are so wound that the end of the first coil connects to the beginning of the second (13 Fig. 252) and so on; from the first and last coils the ends are brought out and thence, by means of cables (18 Fig. 255) or insulated bars secured to the magnet ring, over the hub and along the shaft, the current is conducted from the collector rings (19 Fig. 255). These rings are provided with brushes held in substantial brush-holders carried on brush rods from the carrier arm (13 Fig. 256). The two parts of the carrier arm are insulated from one another and from the frame as it is through these that the D. C. field excitation current is fed by means of the cables indicated at item 14 Fig. 256.

The magnet wheel radial arms (14 Fig. 255) are of cast iron or Siemens-Martin Steel and the shaft (13 Fig. 251) of forged steel. This shaft is carried in two split bearings one in each pedestal (one shown 21 Fig. 255). The lubrication is effected by means of oil rings revolving with the shaft and carrying a copious supply of oil from the oil wells.

The vertical shaft alternator has a top bearing bracket (13 Fig. 257), which rests on the stator frame and supports the thrust bearing, which in its turn carries the rotor. This top bearing bracket also includes the upper guide bearing, which is usually incorporated with the thrust bearing. This guide bearing is intended to work with another guide bearing, which is carried by the lower bearing bracket located beneath the rotor, thus maintaining the rotor in the correct position. Vertical shaft alternators usually have the lubricating system designed so that the oil from the

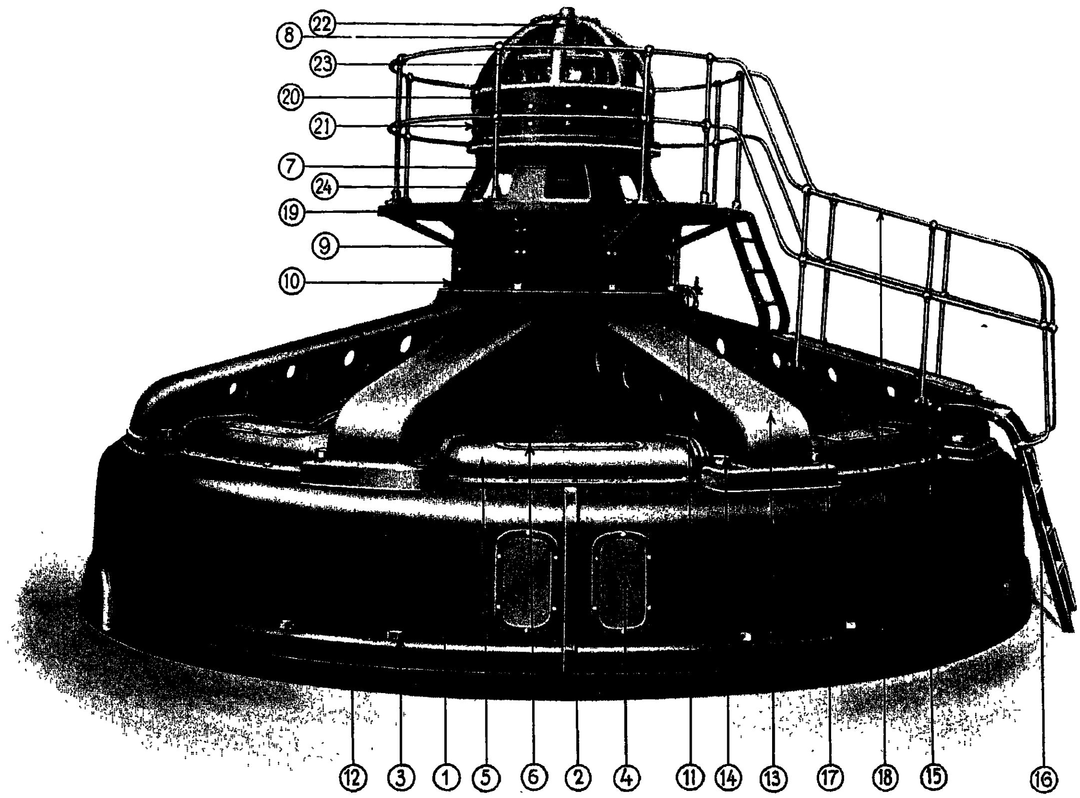


Fig. 257. Vertical alternator, totally enclosed with direct coupled exciter.
1. Stator frame. 2. Stator joint. 3. Bolt. 4. Cover for opening in stator frame. 5. Enclosure, split in segments. 6. Cover for inspection openings in enclosure. 7. Shaft. 8. Alternator brushholder and brush. 9. Top bearing housing. 10. Bearing housing bolt. 11. Oil pipe. 12. Foundation ring 13. Top bearing bracket. 14. Bearing bracket bolt. 15. Enclosure-bolt. 16. Staircase. 17. Gangway. 18. Railing. 19. Platform. 20. Exciter frame. 21. Exciter pole bolt. 22. Brush gear for alternator and exciter. 23. Exciter brush holders and brushes. 24. Exciter base ring.

oil-cup above the bearings drips down upon the thrust bearing. From the latter it runs to the upper guide bearing, after which, in most cases, it is led to the lower guide bearing and thereafter is caught in a container. With the larger vertical machines the thrust bearing is often arranged in an oilfilled bearing-housing, and for this reason the machine is equipped with an oil pump, which drives up the cleansed and cooled oil from the container to be used in the thrust bearing.

The machine is either mounted on one bedplate, carrying both stator and bearings, (20 Fig. 256) or on a separate bedplate (25 and 26 Fig. 255). The vertical arrangement requires the use of a foundation ring (12 Fig. 257), which is securely fastened to the ground and supports the stator frame. The bedplates and foundation rings are of cast iron and are anchored by means of foundation bolts (21 Fig. 256).

SOME LARGE HORIZONTAL GENERATORS INSTALLED IN SWEDEN.

Ordered in	Delivered in	Customer	Number	Type	KVA	R. P. M.	Cycles	Volts
1908	1909	Svenska Statens Kraftverk, Trollhättan	4	G 288	11000	187	25	11000
1909	1911	» » » »	1	G 288	11000	187	25	11000
1911	1912	» » » »	1	G 288	11000	187	25	11000
1912	1913	» » » »	2	G 288	11000	187	25	11000
1916	1917	» » » »	3	G 288	11000	187	25	11000
1917	1918	» » » »	2	G 288	11000	187	25	11000
1919	1920	» » » »	1	G 288	11000	187	50	11000
1920	1921	» » » »	1	G 288	11000	187	50	11000
1913	1914	» » » Porjus	2	G 279	11000	250	25	11000
1917	1919	» » » »	2	G 279	11000	250	25	11000
1911	1914	» » » »	3	G 279	6250	225	15	4150
1913	1914	» » » Älvkarleby	3	G 299	10000	150	50	11000
1914	1915	» » » »	2	G 299	10000	150	50	11000
1920	1921	» » » Motala	2	G 2606	6000	167	50	7000
1915	1917	Stockholms Stads Elektricitetsverk, Untra	4	G 297	9000	125	25	6800
1903	1904	» » » Värtan	3	V 1700	1770	100	25	6500
1920	1921	Gideå-Husums A.-B.	1	G 2307	5550	300	50	6300
1916	1917	» »	1	G 237	4250	300	50	6300
1916	1917	Yngeredsfors Kraft-A.-B., Mölndal	1	G 238	5000	375	25	10000
1916	1917	» » »	1	G 237	5000	375	50	10000
1915	1915	» » »	1	G 208	2850	300	50	4000
1905	1906	» » »	3	V 2400	2350	250	50	4000
1921	1922	Sydsvenska Kraft-A.-B.	3	G 276	5000	167	50	5250
1911	1911	» »	4	G 238	3000	167	50	5250
1907	1908	» »	8	V 330	1420	167	50	5250
1915	1917	Faxälvens Kraft-A.-B., Kramfors	1	G 256	4950	250	50	6600
1919	1920	» » »	1	G 256	4950	250	50	6600
1921	1922	Västerdalälvens Kraft-A.-B., Mockfjärd	1	G 247	4500	250	50	6600
1917	1919	Uddeholms A.-B., Krakerud	2	G 276	4300	150	25	12000
1909	1911	» » Forshultsforsen	3	G 247	2600	187	25	12000
1912	1913	» » »	2	G 247	2600	187	25	12000
1915	1916	» » »	2	G 247	2600	187	25	12000
1917	1919	» » Krakerud	1	G 236	2100	187	25	12000
1920	1921	Holmens Bruks- & Fabriks A.-B., Norrköping	3	G 275	4250	150	50	3000
1920	1920	» » » » Hallstavik	1	G 236	2900	214	50	5000
1907	1908	Gullspång-Munkfors Kraft-A.-B.	1	V 3950	3950	250	50	5000
1916	1917	» »	1	G 237	3950	250	50	5000
1919	1920	» »	1	G 237	3950	250	50	5000
1915	1916	» »	1	G 219	3750	300	50	3300
1906	1907	» »	3	V 3500	3500	250	50	5000
1912	1913	Stora Kopparbergs Bergslags A.-B.	3	G 267	3800	180	60	7000
1908	1909	» » » »	3	G 267	3500	180	60	7000
1920	1920	Skönviks A.-B., Nedansjö	1	G 255	3800	187	50	6300
1916	1917	» » »	1	G 254	2500	167	50	6300
1915	1916	Hissmofors A.-B., Krokom	1	G 238	3750	257	60	11000
1919	1920	» » »	1	G 2306	3750	257	60	11000
1911	1912	Ljunga Verk, Johannisberg	4	G 209	3300	375	50	6300
1911	1912	» » »	2	G 177	1200	500	50	6300

SOME LARGE HORIZONTAL GENERATORS INSTALLED IN SWEDEN.

Ordered in	Delivered in	Customer	Number	Type	KVA	R. P. M.	Cycles	Volts
1917	1917	A.-B. Graningeverken, Forsse	1	G 237	3250	250	50	5000
1915	1915	Asea, Västerås, för provrum	1	G 187	2500	500	50	800
1917	1918	Rydboholms A.-B., Viskafors	1	G 188	2250	375	50	3300
1920	1920	» » »	1	G 188	2250	375	50	3300
1920	1921	Borås Väveri-A.-B., Skene	1	G 207	2250	300	50	2500
1917	1917	A.-B. Heroults Elektriska Stål, Ätrafors	1	G 207	2200	300	50	10000
1918	1919	Svartåfors Kraftstation	1	G 236	2150	187	50	10000
1915	1915	Håvreströms A.-B.	1	G 234	2100	250	50	415
1906	1907	» »	1	V 277	1180	200	50	415
1909	1909	Göteborgs Stads Elektricitetsverk...........	1	G 236	2000	167	25	6600
1907	1908	» » »	2	V 300	1325	187	25	6600
1917	1918	Norrköpings Kommunala Affärsverk	1	G 169	2000	500	50	3000
1920	1921	Hemsjö Kraft-A.-B., Ystad	2	G 273	2000	125	50	6600
1909	1910	Umeå Elektricitetsverk	2	G 208	1950	300	50	6300
1916	1916	Avesta Järnverk	1	G 236	1900	167	50	500
1916	1917	» »	1	G 236	1900	167	50	500
1918	1919	Asea, Ludvikaverken, Ludvika	1	G 188	1850	375	50	7000
1913	1913	Dejefors Kraft- och Fabriks A.-B.	1	G 253	1840	167	50	2000
1914	1914	» » » » »	1	G 253	1840	167	50	2000
1902	1903	Örebro Elektriska A.-B., Brattfors	1	V 1800	1830	214	50	20000
1905	1906	» » » »	1	V 1800	1830	250	50	20000
1920	1920	A.-B. Knutsbro Kraftstation, Bjärka Säby	1	G 207	1800	250	50	3300
1910	1910	» » » Öjebro Kraftstation	2	G 214	1300	300	50	6000
1918	1919	Klosters A.-B., Långshyttan	1	G 1810	1760	490	16	3500
1916	1916	A.-B. Bofors-Gullspång	2	G 207	1750	250	50	8400
1920	1920	A.-B. Svenska Denofa, Nödinge.............	2	G 186	1750	500	25	6000
1920	1920	A.-B. Papyrus, Mölndal	1	G 167	1350	500	50	800
1913	1914	Odensfors Kraftstation	2	G 224	1300	250	50	10000
1914	1915	Oxelösunds Järnverks A.-B.	3	G 300	1300	94	50	3150
1917	1918	Rydö Bruks & Fabriks A.-B., Rydöbruk	1	G 168	1300	600	50	5400
1915	1916	Långeds A.-B.	1	G 205	1250	300	50	5000
1907	1908	» »	2	V 277	1000	300	50	5000
1916	1917	Fagersta Bruks A.-B.	1	G 233	1250	187	50	2000
1909	1910	» » »	2	G 223	1040	250	50	2000
1916	1917	Finsjö Krafts A.-B., Blanka Kraftverk, Lillsjödal	1	G 205	1250	250	50	6600
1919	1919	» » » » » »	1	G 205	1250	250	50	6600
1916	1917	» » » Hornsö.................	1	G 185	1250	375	50	6600
1914	1914	Sandvikens Järnverks A.-B.	1	G 149	1200	600	50	520
1911	1911	Skärblacka A.-B., Fiskeby	1	G 243	1100	125	50	800
1903	1904	» » »	1	V 1000	1000	115	50	800
1916	1917	Stockholm-Roslagens Järnvägar.............	1	G 148	1100	750	50	3300
1920	1920	Bergvik & Ala Nya A.-B., Vifors kraftverk ..	1	G 149	1100	600	50	3150
1920	1921	Oxelösund-Flen-Västmanlands Järnväg	1	G 149	1080	750	50	3000
1911	1911	Hjerpens Cellulosafabrik...................	1	G 213	1000	250	50	3300
1913	1914	Elvestorp Kraftstation	1	G 213	1000	214	50	525
1915	1916	Skogshalls Sulfitfabrik	1	G 158	1000	750	25	525
1916	1916	Obbola Sulfitfabrik	1	G 205	1000	214	50	3000

SOME VERTICAL GENERATORS INSTALLED IN SWEDEN.

Ordered in	Delivered in	Customer	Number	Type	KVA	R. P. M.	Cycles	Volts	Thrust-bearing load kgs.
1896	1896	Dr. De Laval, Trollhättan	1	AC 2.5	850	250	12.5	300	11000
1897	1897	» » » »	1	AC 2.5	850	250	12.5	300	11000
1916	1917	Per Holms El. Verk, Löfön	1	GS 250	800	125	50	10000	—
1903	1904	» » » » »	1	VIS 1.25	225	125	50	10000	4300
1909	1910	» » » » »	1	VS 291—26	225	125	50	220	5100
1906	1906	Frykfors A.-B., Fagerås	3	VCS 1.5	750	150	50	2000	11300
1911	1911	» » »	1	VCS 1.5	750	150	50	2000	11300
1914	1915	Östersunds El. A.-B., Hissmofors	1	GS 176	740	300	60	330	3800
1901	1901	» » » »	2	VLS 4.5	210	450	60	330	—
1905	1905	Hissmofors A.-B., Krokom	1	VES 2.57	546	257	60	330	4600
1906	1906	» » »	1	VES 2.57	546	257	60	330	4600
1910-1913	1910-1914	Horndals Järnverk, Näs	8	GS 244	575	88	50	660	12500
1901-1906	1901-1907	» » »	11	VES 2.14	415	214	50	660	5000
1898	1898	» » »	2	VGS 1.67	255	167	50	660	—
1898	1898	» » »	1	VAS 3.75	102.5	375	50	660	—
1912	1913	Forshaga Sulfitfabrik	1	GS 251	550	75	50	500	28000
1918	1919	Wahlquistska Klädesfabriken, Svängsta	1	GS 232	550	94	50	400	18500
1920	1920	» » »	1	GS 181	275	150	50	400	10000
1906	1907	Motala Ströms Kraft-A.-B., Klockrike	1	VES 1.07	485	107	50	800	11000
1915	1916	» » » »	1	GS 204	485	107	50	850	11000
1903	1903	» » » »	4	VIS 1.07	250	107	50	800	7300
1904	1905	Bergvik & Ala Nya A.-B.	1	VES 0.75	440	75	50	3000	8000
1901	1902	» » » » »	2	VES 0.94	440	94	50	3000	—
1913	1914	Norbergs El. A.-B., Kärrgruvan	1	GS 210	287	107	50	780	15000
1899	1899	» » » Avesta Lillfors	3	VIS 0.75	200	75	50	780	6000
1904	1905	» » » » »	1	VIS 0.75	200	75	50	780	6000
1901	1902	Gysinge Bruks A.-B.	1	AIS 0.75	270	75	15	3000	—
1920	1921	Bultfabriks A.-B., Hallstahammar	1	GS 201	250	125	50	400	12750
1913	1913	» » »	1	GS 191	200	125	50	400	12000
1904	1905	Surahammars Bruks A.-B.	2	VIS 0.7	248	70	60	380	8200
1906	1906	Oskarsströms Sulfitfabrik	3	VIS 1.36	247	136	50	820	3500
1914	1915	Klippans Finpappersbruk	1	GS 174	225	187	50	5250	10000
1903	1904	Umeå Stads El. Verk, Klabböle	1	VIS 1.87	222	187	50	5200	3000
1899	1899	» » » » »	2	VIS 2.14	220	214	50	5200	—
1897	1897	Fagersta Bruks A.-B., Semla	2	VGS 1.07	210	107	50	2250	—
1900	1900	» » » Västanfors	2	VGS 1.07	180	107	50	2080	—
1900	1900	» » » Semla	1	VLS 1.76	150	176	50	2080	—
1906	1906	Söderfors Bruks A.-B.	3	VIS 1.0	180	100	50	295	7200
1899	1899	» » »	2	VGS 1.07	175	107	50	295	—
1896	1897	Ramnäs Bruks A.-B.	1	VLS 2	170	200	50	1560	—
1907	1907	P. Swartz, Norrköping	2	VS 291—21.5	165	94	50	525	4500
1915	1915	J. G. Swartz »	1	GS 191	160	94	50	525	2500
1915	1915	» »	1	GS 163	160	150	50	525	2500
1909	1909	Ohs Kraftstation, Alfvesta	1	VS 211—27.5	130	214	50	6600	4500
1899	1899	Köpings El. Verk, Köping	2	VAS 2	108	200	60	3450	—
1907	1907	Mölneby A.-B., Axelfors	1	VS 211—17.5	107.5	150	50	400	3700

SOME LARGE HORIZONTAL GENERATORS INSTALLED ABROAD.

Ordered in	Delivered in	Customer	Number	Type	KVA	R. P. M.	Cycles	Volts
1919	1921	Norske Statens kraftanlæg, Glomfjord, Norway	1	G 2713	24000	300	25	15000
1916	1919	» » » » »	2	G 2711	22000	300	25	15000
1913	1915	A/S Rjukanfos, Norway	6	G 2711	18900	250	50	9500
1909	1910	» » »	5	G 2610	17000	250	50	11000
1921	1922	Akershus Amts El.-verk, Raanaasfos, Norway	2	G 3009	12000	107	50	7500
1911	1913	A/S Svælgfos, Norway.....................	1	G 2610	11000	250	50	11000
1913	1914	» » »	1	G 2610	11000	250	50	11000
1906	1907	» » »	4	V 10500	10500	250	50	11000
1916	1918	A/S Bjölvefossen, Aalvik, Norway...........	3	G 2312	10750	375	50	12000
1919	1920	Trondhjems El.-verk, Övre Lerfoss, Norway..	1	G 2306	5000	375	50	7000
1919	1920	» » Nedre » » ..	1	G 235	3000	375	50	7000
1917	1918	Onega Kvävoxidfabrik, Kiwatsch, Russia	1	G 2010	4750	375	50	2200
1917	1918	» » » »	1	G 168	1650	600	50	2200
1912	1912	Arendals Fossekompani, Norway...........	3	G 238	4670	375	25	5000
1913	1914	» » »	3	G 238	4670	375	25	5000
1912	1912	» » »	1	G 228	4375	375	50	5000
1906	1908	A/S Tyssefaldene, Tyssedal, Norway	6	V 4100	4100	375	25	12000
1909	1910	» » » »	1	V 4100	4100	375	25	12000
1917	1918	H.E.P.C. of Ontario, Healey's Falls, Canada ..	1	G 255	3750	240	60	6600
1912	1913	Eddy Co. Hull, Que., Canada	3	G 275	3750	163	60	2300
1911	1912	Nokia A.-B., Finland	1	G 256	3600	167	50	5250
1917	1917	Drammens El.-verk, Labro, Norway	1	G 236	3600	375	50	5000
1920	1921	Tammerfors L.-& J.-A.-B. Anjalakoski, Finland	4	G 274	3500	150	50	6300
1918	1918	A/S Sulitelma Gruber, Norway	1	G 208	3000	375	50	5000
1904	1905	Tinfos Papirfabrik, Norway	1	V 2830	2830	250	50	5150
1906	1907	» » »	1	V 2830	2830	250	50	5150
1920	1921	Mandals Elektricitetsverk, Norway	1	G 188	2700	750	50	5250
1919	1920	» » »	1	G 169	1820	750	50	5250
1915	1916	Norsk Motor og Dynamofabrik, Norway	1	G 187	2500	500	50	800
1913	1913	Sagami Hydro El. Power Co., Japan	3	G 189	2500	500	50	6600
1913	1913	» » » » » »	3	G 186	1500	500	50	6600
1919	1920	Tromsö El.-verk, Skarsfjord, Norway	1	G 186	2100	750	50	6000
1918	1919	A/S Björkåsens Gruber, Norway	1	G 186	2000	600	50	5500
1920	1921	The Sneyd Collieries, England	1	G 188	2000	750	25	480
1920	1921	Kangas Pappersbruk, Finland	2	G 233	2000	300	50	6300
1920	1920	Kamfos Kraftanlæg, Norway	1	G 187	1850	500	50	11000
1919	1919	Tyssebotn Kraftanlæg, Osteröen, Norway	1	G 187	1820	500	50	10500
1916	1917	Follum Träsliperi, Hönefos, Norway	1	G 205	1750	300	50	515
1920	1920	» » » »	1	G 205	1750	300	50	515
1916	1916	Hellerens Kraftanlæg, Norway	1	G 188	1650	500	25	12000
1914	1915	Electrica del Cinca, Spain	1	G 224	1500	250	50	2500
1919	1919	Nordland Portland Cement A/S, Norway	1	G 167	1500	750	50	5500
1910	1910	Seymor Power Co, Canada	1	G 263	1250	120	60	2400
1915	1916	E. D. Sassoon & Co, Bombay, India	1	G 252	1250	150	50	460
1916	1916	Kajana Wood Co, Finland.................	2	G 234	1250	167	50	10000
1915	1915	Embretsfos Fabrikker, Norway.............	1	G 213	1200	300	50	10000
1913	1914	Hijos de Bartolomeo Recolons, Barcelona, Spain	1	G 168	1200	600	50	5500
1917	1917	Elverums Elektricitetsverk, Norway	1	G 232	1100	214	50	5500
1916	1916	A. Ahlström O. Y., Warkaus, Finland	1	G 233	1100	187	50	3150

SOME LARGE HORIZONTAL GENERATORS INSTALLED ABROAD.

Ordered in	Delivered in	Customer	Number	Type	KVA	R. P. M.	Cycles	Volts
1919	1919	Eidefos Kraftanlæg, Norway	1	G 185	1050	375	50	5000
1911	1911	Böhnsdalens Mills Ltd, Norway	1	G 223	1030	214	50	525
1902	1903	A/S Barbu, Norway	1	V 1000	1000	125	50	2000
1902	1904	» » »	1	V 1000	1000	125	50	2000
1912	1912	Electrica del Segura, Spain	1	G 213	1000	250	50	4600
1911	1912	Salvesen & Thams A/S, Thamshavn, Norway	1	G 148	1000	750	50	1100
1919	1920	Vinger Kommunale El.-verk, Aabogen, Norway	2	G 149	1000	750	50	5500

SOME VERTICAL GENERATORS INSTALLED ABROAD

Ordered in	Delivered in	Customer	Number	Type	KVA	R. P. M.	Cycles	Volts	Thrust-bearing load kgs.
1918	1919	A/S Vittingfos Kraftanlæg, Norway	1	GS 276	4800	187	50	5000	65000
1919	1919	» » » »	1	GS 276	4800	187	50	5000	65000
1913	1913	Calgary Power Co., Canada	2	GS 277	4250	163	60	12000	—
1919	1920	Hönefos Kommunale El. Verk, Norway	1	GS 274	4000	214	50	6600	61000
1913	1914	Ortario Light & Power Co., Canada	2	GS 253	1250	150	60	11000	25200
1919	1920	Björneborgs Kraft-A.-B., Äetsö, Finland	4	GS 272	1250	88	50	3150	52400
1920	1920	» » » »	1	GS 272	1250	88	50	3150	52400
1919	1920	C. A. Mengemor, Mengibar, Spain	1	GS 185	1000	300	50	3000	22800
1910	1911	Sidney El. Power Co., Trenton, Canada	4	GS 253	940	120	60	6600	—
1911	1912	» » » » » »	4	GS 253	813	112.5	60	7000	—
1909	1909	Cobalt Power Co., Hound Chute, Canada	3	VCS 1.5	875	150	60	11000	12000
1911	1911	» » » » » »	1	VCS 1.5	875	150	60	11000	12000
1921	1921	C. A. Dynamis, Valencia, Spain	1	GS 185	800	250	50	1650	—
1913	1914	Hidro El. del Genil, San Calixto, Spain	1	GS 213	450	90	45	1000	4500
1913	1913	» » » » » » »	1	GS 212	360	90	45	1000	4200
1920	1921	» » » » El Baltan »	1	GS 231	405	84.5	45	1000	4000
1913	1914	H.E.P.C. of Ontario, Wasdells Falls, Canada	2	GS 233	400	90	60	2300	6500
1910	1911	Pankakoski Träsliperi, Finland	1	GS 173	340	300	50	500	5200
1912	1912	» » »	1	GS 173	340	300	50	500	5200
1914	1914	Issupowo Power Station, Russia	1	GS 174	2[illegible]0	150	50	525	—
1898	1899	Ladoga Bergverks A.-B., Finland	2	VGS 1.07	215	107	50	620	—
1908	1909	Iroquois, Canada	2	VS 291—21.5	210	97.5	60	2300	4500
1912	1912	» »	1	VS 291—21.5	210	97.5	60	2300	10500
1907	1907	Owen Sound, Canada	1	VS 211—23.5	175	200	60	6600	3250
1911	1912	Walkerton Light & Power Co., Canada	1	GS 191	150	120	60	2300	8000

CONTENTS.

Pamphlet No. 560.

PAMPHLET No 571

ASEA

AUTOSYNCHRONOUS MOTORS

ALLMÄNNA SVENSKA ELEKTRISKA AKTIEBOLAGET

VÄSTERÅS – SWEDEN

AUTOSYNCHRONOUS. MOTORS

Since the early eigthies when alternating current was first used for the transmission and distribution of electric energy for lighting purposes, the inductive influence of transmission lines — which produces phase displacement between voltage and current in the lines and machines connected in circuit — has been known. The disadvantage of such phase displacement were however not fully realized until the threephase system, with induction motors, was introduced in the early nineties. Every attention has since been paid to the design, construction and proportioning of induction motors to minimise this phase displacement, but in spite of all efforts the fact remains that most electrical power installations suffer from a large phase displacement which has necessitated special precautions being taken to reduce this by increasing the power factor of the installation.

A bad power factor is obviously a great disadvantage in any A.C. system; it necessitates larger generators, transformers and cables, causes increased losses and bad regulation. It is due principally to the presence of inductive plant on the network (such as motors and transformers) which cannot supply their own magnetising current but have to draw this from the generators via the cables and conductors. To compensate for the phase displacement caused, this magnetising current must be supplied from some other source and this source should be as near as possible to the place or machine where it is required to apply same, thus reducing losses in the conductors. This magnetising current can be in the form of D.C. or A.C. — in the latter case either the same frequency as the supply or lower. If D.C. or low frequency A.C. is used the machine producing same must be driven by a motor or equivalent device.

The different forms of apparatus used for power factor correction are: —

1. Condensers.
2. Compensators and Vibrators.
3. Synchronous and Autosynchronous Motors.

Condensers are occasionally used and connected to the circuit at the most suitable position; at present they can only be used in single units when the voltage is in the neighbourhood of 600 and if materially above or below this figure transformers have to be installed to operate in conjunction with them — an obvious drawback. They are also relatively expensive consequently their application is limited.

The phase advancer, and vibrator, provide a leading current of low frequency which is led into the rotor of an ordinary induction motor; the former consists of a commutator machine driven either by the main motor or a separate auxiliary motor. The leading current supplied by this is proportional to the secondary current of the main motor and consequently varies from zero at no-load to a maximum at full load. This introduces the disadvantage that there is no correction at no-load and the motor takes its magnetising current from the supply mains. The same thing applies to the ordinary form of vibrator. This consists essentially of three armatures each in its own D.C. field and connected one across each phase of the rotor circuit of the main motor. The rotor current causes them to

oscillate in synchronism with its own frequency and a leading current is thus generated due to their own inertia. With the Kapp form of vibrator another disadvantage is that a D.C. supply is required to energise the armature fields.

Before dealing with the third and most important method of power factor correction or studying closely the possibilities of utilising synchronous motors, or more particulary autosynchronous motors, it should first be explained more precisely and in some detail the meaning and importance of

Cos. φ

The angle φ is the phase angle referred to above between the voltage and current in an alternating current system as shown in a vector diagram and the cosine of this angle is the figure (never greater than 1) which indicates to what degree the electromagnetic energy in the lines, machines and transformers is effectively utilised; that is the reason why this is now generally termed "Power factor". It must not be assumed that the portion of the energy *which is not effectively* utilised is actually lost, but this portion certainly circulates throughout the system passing the point or points where the energy is consumed and returning to the power source through the corresponding conductors, apparatus etc. At first glance it might appear as if no harm was done when this particular form of energy is circulated in the system and returned to the source. Here however lies the great disadvantage of a low power factor, as the whole installation including generators, transformers, transmission lines and apparatus must have a larger current carrying capacity and be sufficiently dimensioned for both the effective energy consumed and the non-effective energy returned. In addition to this the losses in the various parts of the complete installation are dependent on the resistance of same and the square of the current; these are real losses corresponding to the *total energy* trasmitted whether consumed or circulated. In this way a low power factor will unnecessarily increase the first cost of an electric installation and in addition increase the running cost of same. Such energy which — on account of the cos φ being less than 1 — is thus returned to or reacts on the power source, is often called "Reactive energy" in contradistinction to the consumed power termed "Active energy". If, for example, the power factor of an electric installation is 0.75 this really means that 75 % of the generated and transmitted power is utilised and consequently active, whereas 25 % is sent back and is consequently reactive. It necessarily follows that if one could increase the power factor from 0.75 to 1, an additional 33 % of useful energy could be obtained from this plant without in any way increasing the electrical proportioning of same, and in certain respects this could even be reduced. As a power factor as low as 0.75 is quite usual in practice, the above example clearly emphasises the necessity of taking effective steps to increase the power factor of such electric installations, which matter has during recent years been most seriously considered in its various aspects by Central Station Engineers. A simple solution of the problem will have far reaching effects and whilst already of importance to all distributors and users of electric energy it will be more so in the future.

An important fact in this connection is that the Supply Companies and Authorities now fully realise the great drawbacks of a low power factor on their supply nets and are already introducing more stringent regulations with the object of making their charges on a different basis by penalising consumers with low power factors in such a way, that, in addition to the usual kW/hour meter measuring the effective energy a similar meter is installed measuring the reactive energy. When this latter exceeds a certain pre-determined value — depending on the size and nature of the consumer's installation — a charge will also be made for additional units of reactive energy in accordance with special schedules prepared by the Supply Company. No doubt changes will very soon be made in most Supply Company's charges on somewhat similar lines to those indicated above with the same object in view.

An effective means of increasing the power factor is by utilising a machine or device which can neutralize to a large extent the reactive effect, in such a way that it need not be produced in

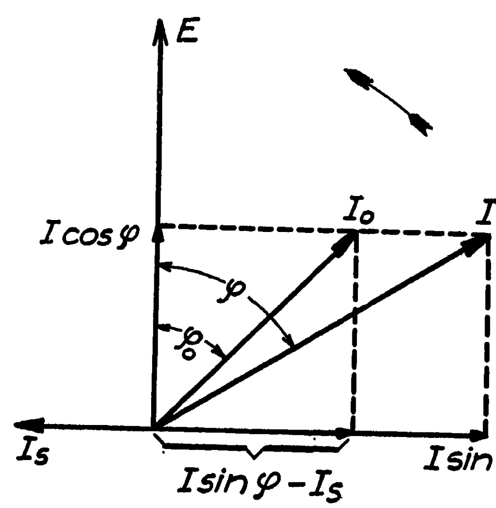


Fig. 1.

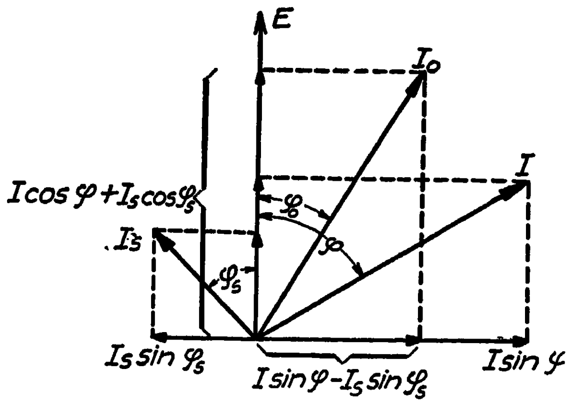


Fig. 2.

the Power House or transmitted from there to the place of consumption; in other words, if the machine or device is on the consumer's premises it can be made to produce a contra reactive effect of corresponding magnitude. Such an arrangement is found in the over-excited or over-magnetised synchronous motor.

Synchronous Motor.

A vector diagram best demonstrates the property which this motor possesses of increasing the power factor of a certain energy demand. As an example, if at the place of installation where the energy is consumed by synchronous or induction motors, the voltage is "E", the required current "I" and the phase displacement on account of the characteristics and load on these motors is φ, the active effect or energy component will be (see Fig. 1).

$$P_a = E \cdot I \cos \varphi \text{ watt,}$$

and the reactive effect or wattless component.

$$P_{re} = E \cdot I \sin \varphi \text{ rewatt.}$$

In this pamphlet the reactive energy is called "rewatt" so as to indicate its reactive nature, consequently reactive units or kW hours are styled kilo rewatt hours.

If now at this point a synchronous motor running at no load is put in circuit in parallel with the other motors, and this motor is over-excited, its current I_s will be vectorially in an opposite direction to $I \sin \varphi$, in other words, it is anti-reactive (or negatively reactive). This current will reduce the value of $I \sin \varphi$ in such a way that the balance of the reactive current is $I \sin \varphi$ minus I_s. In this way the total current I_o is obtained which is less than the original (I) and the new phase angle φ_o is also less than the original φ, as a result of which cos φ has been increased a corresponding amount. The wattless component or reactive effect has been reduced by an amount equal to that given by the synchronous motor.

$$E \cdot I_s \text{ rewatt}$$

The synchronous motor need not however run without load to obtain this advantage but can at the same time be used to do actual work.

Figure 2 shows a vector diagram under the latter conditions.

The active effect or energy component of the synchronous motor is now

$$E \cdot I_s \cos \varphi_s$$

and its reactive effect or wattless component

$$E \cdot I_s \sin \varphi_s$$

when φ_s is the leading phase angle. The resulting current is now I_o with a phase displacement φ_o.

In this way it is easy to ascertain the influence of the over-excited synchronous motor on the total power factor under different conditions. For instance, if the synchronous motor has a variable load ($E \cdot I_s \cos \varphi_s$) it is necessary to know how its reactive current $I_s \sin \varphi_s$ varies in order to determine its influence or, in other words, how one ought to vary its reactive current (dependent upon the field current of the synchronous motor) to obtain the desired result in respect of cos φ etc. (Needless to say when three-phase is in question it is essential to multiply by three or $\sqrt{3}$ if E is volts per phase or between phases respectively, in order to obtain the correct result.) The following question might here be asked: — Is the advantage obtained by increasing the power factor more than the total extra cost (initial cost plus operating costs) of an over-excited synchronous motor in comparison with an ordinary induction motor? This question can, without hesitation, in practically every case be answered in the affirmative and generally speaking it is found that the extra cost of the synchronous motor is more than balanced by the gain at the generator end and that the real profit is secured in the reduction of losses in, or initial cost of conductors or cables, transformers and apparatus, and, last but not least, in an improved voltage regulation on the whole system. This is of course on the assumption that the synchronous motor is connected at the place of power consumption and suitably designed for its work. It is well-known that the synchronous motor is unsuitable in cases where increased slip is required at heavier loads, for example, when working in conjunction with a flywheel. Neither is a synchronous motor suitable where repeated stopping and starting is required, but on the other hand,

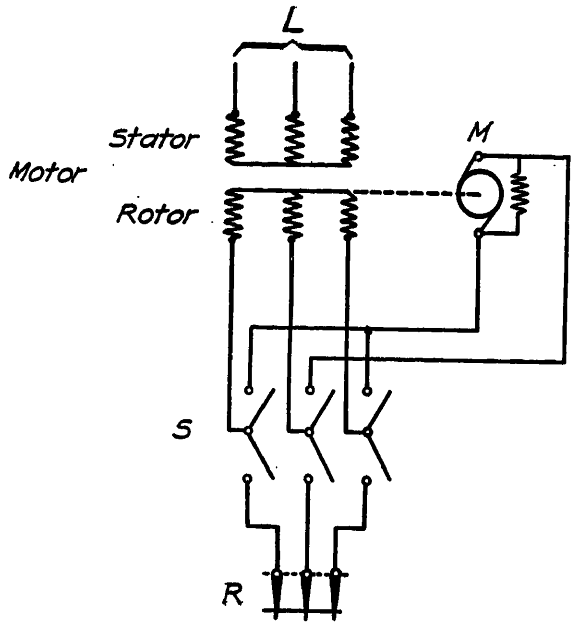


Fig. 3.

the asynchronous motor under such conditions is an ideal machine.

It is obvious from what has been stated above that the ideal motor for power factor correction purposes, which at the same time performs useful work would be a machine having the starting and running characteristics of an asynchronous motor and the phase compensating characteristics of a synchronous machine. These ideal characteristics are all combined in the subject of this article, viz: the

Autosynchronous Motor.

This motor was invented in 1900 by the world-renowned Swedish Electrical Engineer, Mr. Ernst Danielson, at that time Chief Technical Engineer of Allmänna Svenska Elektriska Aktiebolaget, Västerås, Sweden. The term "autosynchronous" really means a synchronous motor which "auto"matically gets into synchronism. A short description of its design and characteristics will show in what respects its name applies.

From the diagram (Fig. 3) it will be seen that the motor is fundamentally an asynchronous or induction motor, as a rule a three-phase one. "L" is the supply net to which the motor is connected, "S" a three-pole throw-over switch which is closed "downwards" when starting the machine. The resistance "R" in the rotor circuit is connected in the usual way and when gradually cut out the motor starts up as an ordinary induction motor and runs at a speed of a few per cent below the synchronous one. The direct coupled exciter "M" has now its normal voltage and when in the following operation the throw-over switch is moved rapidly to the "up" position the rotor is magnetised with direct current from "M" and its speed is then automatically accelerated up to synchronism. The voltage on the exciter "M" is then adjusted so as to overmagnetise the rotor in order that the machine should give the required reactive current, with the result stated above, i. e. increase of the power factor of the net.

From the above it will be noted that the rotor being furnished with a threephase winding it starts up exactly like an induction motor: it accordingly has the same starting torque, or even greater, since the autosynchronous machine can be designed with a larger air gap, the no-load losses being compensated by the D.C. magnetisation supplied. In the three rotor phases of an induction motor having a sinusoidal field the currents vary according to a sine curve, as is well known and at each instant the current in one phase I_1 is equal to the sum of I_2 and I_3 in the other two phases, as indicated on Fig. 4.

Such a case where the currents I_2 and I_3 in these two last are equal and fixed is arranged on an induction motor by supplying D. C. to one phase connected in series with the other two in parallel, see Fig. 5.

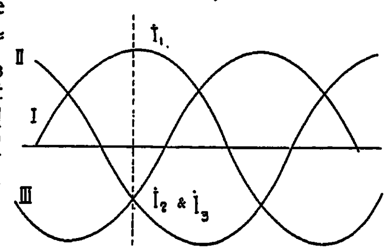


Fig. 4.

Here the flux is as nearly as possible of sine form — compare the field curve Fig. 6 and the no-load voltage curve of a generator Fig. 7. In this way when magnetised with continous current the flux becomes zero in the middle of the phase carrying double current, (see Fig. 8) and as the flux density is low the slots can be made wider thereby providing space for the insertion of heavier conductors. The rotor is accordingly manufactured in a special manner the slots being stamped out in an equal number of groups to the number of poles, each group being composed of one-third wide and two-thirds narrow slots with the windings distributed accordingly.

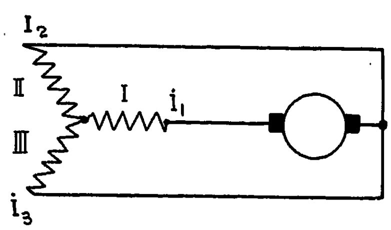


Fig. 5.

Apart from certain inherent characteristics with regard to overload capacity etc. the only

difference between this motor and an ordinary induction motor is that the winding of one phase of the rotor has about double the copper section of the others, as the current in same is twice the magnitude of the current in either of the others and this is quite easily arranged as the rotor slots are also specially dimensioned in the

Fig. 6.

manner described above. It is obvious that the exciter need not necessarily be direct coupled to the motor and also that direct current can be supplied from any other source so long as the correct voltage and current is obtained. As the voltage of the rotor winding during starting must be kept reasonably low the required direct current will also have a low tension with consequent high amperes.

The D.C. required for magnetising is approximately double the current I_2 in the rotor secondary when running as an induction motor taking the same kVA. The copper section in the narrow slots is accordingly normal and need only be increased in the broader ones. If the design is such that the current density is the same in all conductors the resistance as a D.C winding is the resistance per phase in the corresponding induction motor. This resistance is

$$\frac{P \cdot s}{(1-s) \cdot 3 \cdot I_2^2}$$

where s is the induction motor slip and P the kVA of the motor. The exciter voltage is accordingly

$$2 \cdot I_2 \cdot \frac{P \cdot s}{(1-s) \cdot 3 \cdot I_2^2} = 1.15 \cdot E_2 \cdot \frac{s}{1-s}$$

or $= 1.15 \cdot E_2 \cdot s$ where s is small. E_2 is the rotor voltage between sliprings at standstill. The D.C. power required is

$$2\ I_2 \cdot 1.15 \cdot E_2 \cdot s = \text{approx. } 1.33 \cdot P \cdot s.$$

The exciter data therefore becomes

$$\text{Current} = I = 1.15 \cdot \frac{P}{E_2} \text{ amps.}$$

$$\text{Voltage} = E = 1.15 \cdot E_2 \cdot s \text{ volts.}$$

$$\text{Power} = 1.33 \cdot P \cdot s \text{ watts.}$$

To overcome to some extent the drawback of low voltage and heavy current in the rotor circuit the rotor winding can be divided into two groups for starting purposes of which only one may be used during the starting period or the two groups may be put in parallel and series. Another arrangement is often used by which

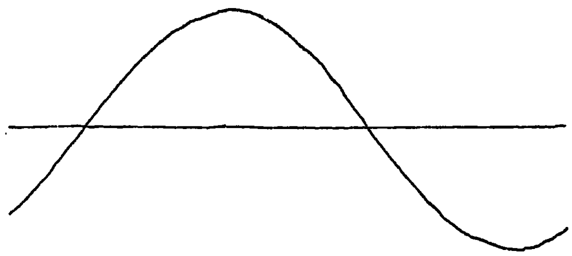


Fig. 7.

the three phases in the rotor are Delta connected during starting and Star connected when running as shown in Fig. 9. In such a case it is necessary to furnish the rotor with six sliprings of which three marked 1, 2 and 3 in Fig. 9 are provided with a brush lifting and short circuiting device.

Generally in a large motor the slipring voltage cannot be higher than about 1200 and to take a specific case with a motor of 1000 kVA and $s = 0.015$ the exciter provides approximately 960 amps at 21 volts. If the Delta Star combination referred to above is used with such a machine the exciter current in this paticular example would be reduced to about 550 amps and the voltage increased to about 36 — a much more satisfactory arrangement.

Regarding the running characteristics of the autosynchronous motor, it should be noted that if the machine is overloaded above its maximum rating as a synchronous motor it falls out of step and, provided the overload is not too large, it continues to run as an asynchronous motor until the load is decreased to an amount just below that at which it fell out of step, when the motor again automatically synchronises itself. During this period the motor runs at a lower speed corresponding to the slip of the rotor. Should the motor on account of heavy load or large flywheel effect of the driven machines (especially if the motor is direct coupled to same) not be able to synchronise itself, a temporary increase of the excitation voltage will generally effect the desired result.

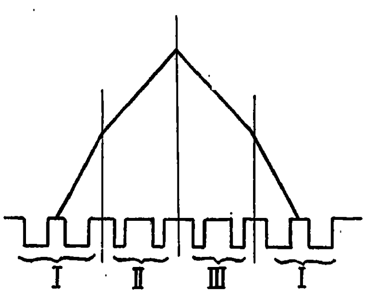


Fig. 8.

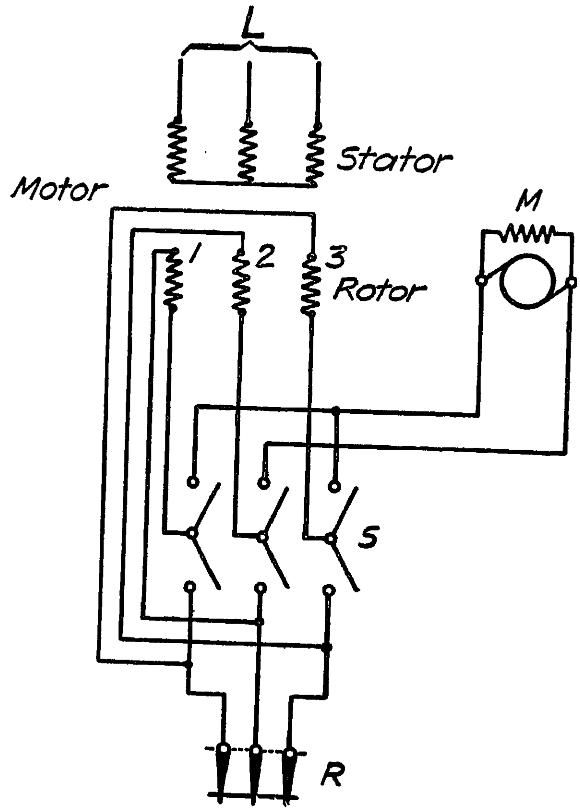


Fig. 9.

In order to fully appreciate how the autosynchronous motor operates it is important to know its inherent characteristics and, as same are best shown graphically, the following will explain briefly in a popular form the working diagrams of the autosynchronous motor and finish off with a short discussion on the points resulting from same, followed by a few practical hints on their applications.

Working diagram and Characteristic Curves of the Autosynchronous Motor.

Fig. 10 shows the working diagram of the motor where "I" indicates the magnitude and phase of the leading primary current; E_p *(OF)* the magnitude and phase of the supply voltage, which is of course equal to the voltage at the motor terminals; *E (OG)* the voltage which according to Fig. 11 corresponds to the magnetising current I_l in the rotor, and *XI (FG)* the synchronous reactance voltage. If in Fig. 11 *OAB* is the no-load characteristic of the machine running as generator and I_{lo} and I_l are, respectively, the exciting current in amperes at no load as generator and at the load as autosynchronous motor indicated in Fig. 10 then the magnitude of *E* is shown in Fig. 11 by *EO*, and

$$\frac{E}{E_p} = \frac{I_l}{I_{lo}}$$

The reluctance of the magnetic circuit is then assumed constant and equal to that existing at the voltage E_p and the magnetising current I_{lo}.

Further if *OD* in Fig. 11 represents the short circuit characteristic of the machine as generator, I_{ko} *(FD)* is the current which on short circuit corresponds to the magnetising current I_{lo} and consequently the synchronous reactance

$$X = \frac{E_p}{I_{ko}} = \frac{AF}{DF}$$

The semi-circle *OBA* in Fig. 10 has a diameter $\frac{E \cdot E_p}{X}$ corresponding to the maximum active power of the motor (per phase if *E* and E_p are phase voltages) and the vector *OB* cut off *E (OG)* is the active power P_a developed by the motor at that moment. P_a is then equal to $\frac{E \cdot E_p}{X} \cdot \sin \gamma$ where γ is the angle between *E* and E_p. The angle φ indicates the phase displacement between supply voltage E_p and current *I*, which angle is negative and consequently will produce the required power factor correction so long as *FG* lies above *FC*. The active current component I_a is obviously proportional to *FH* and

$$I_a = \frac{FH}{X}$$

and the reactive current component $I_{re} = \frac{FK}{X}$

As *FH* is proportional to the active current the area represented by the rectangle *FHMO* is

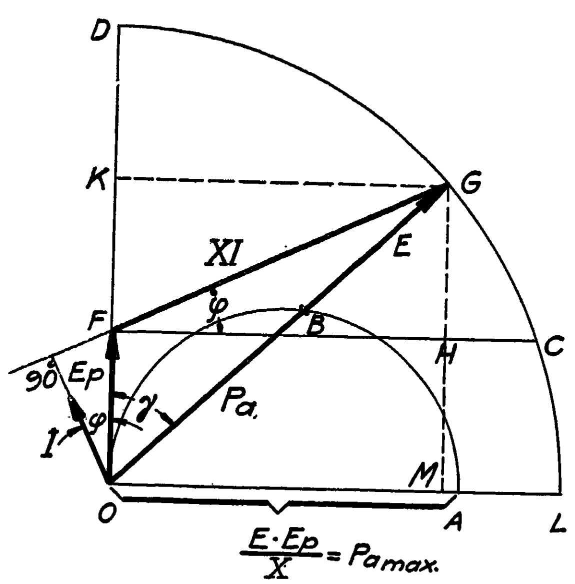


Fig. 10.

obviously proportional to the active power and consequently at constant voltage simply proportional to *FH*.

By studying this diagram the working of the motor can easily be followed. If the D.C. magnetising current is kept constant, and the motor load is varied between zero and maximum, *E* (*OG*) will also be constant, but turn round 0 describing a quarter circle *DGCL*. The vector *FG* will at the same time turn round *F* with its other end on the same quarter circle, while φ changes from $-90°$ at no load to a certain positive value at the maximum load. It is of special interest to note how at the same time the reactive current component changes from its maximum value $\frac{FD}{X}$ at no load to $\frac{FK}{X}$ at normal full load, then to zero when *XI* coincides with *FC* (when $\cos\,\varphi = 1$) and finally to $\frac{FO}{X}$ at maximum load. In this latter case the reactive component is negative and consequently has an inductive influence, reducing the power factor of the plant as a whole.

In order to further illustrate these conditions Fig. 12 shows curves drawn up showing the power factor and current (total and reactive) in the motor as a function of the power P_a when this varies from nil to its maximum value — $P_a \text{ max.} = \frac{E \cdot E_p}{X}$. Normal full load has here been assumed to be 77 % of the maximum load and *E* is assumed to be equal to 4 E_p i. e. the magnetising current at normal full load is four times as large as the magnetising current required at no load with unity power factor. Within this

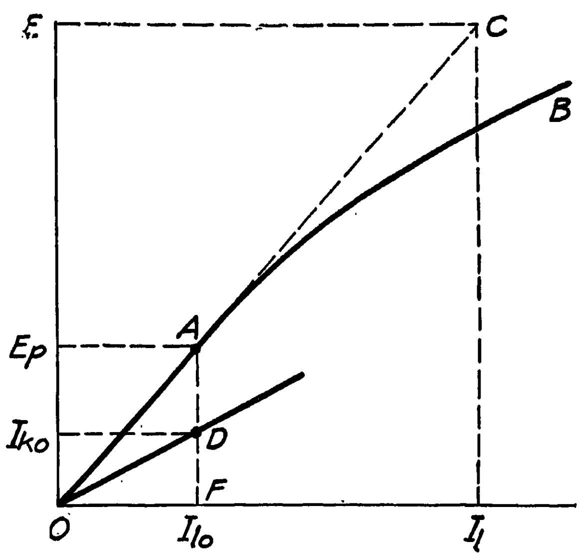


Fig. 11.

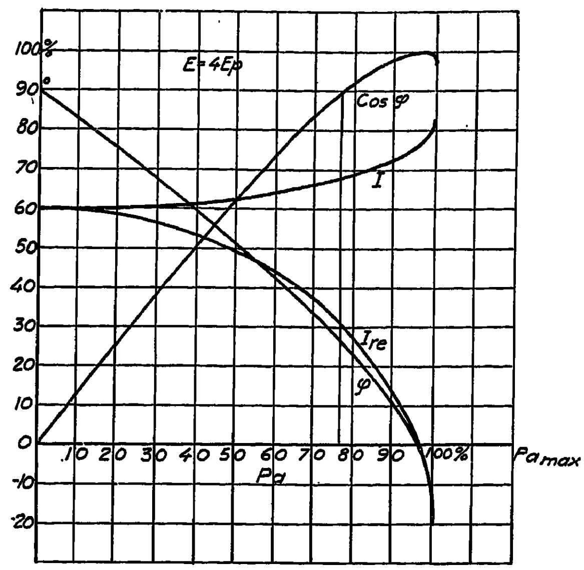


Fig. 12.

load variation the total primary current only varies in the ratio of 60 to 68, the reactive component however from 60 to 30, φ from 90° to 26° and finally the power factor of the motor from 0 to 0.9. The overload capacity is $\frac{23}{77} \cdot 100 = 30\,\%$.

The mechanical power produced by the motor is of course equal to the electrical power P_a less the losses in the motor caused by resistance, hysteresis, foucault currents, windage and friction. As speed, magnetising current and terminal voltage are constant, and the primary current nearly constant, the total losses will be practically constant and consequently the difference between electric and mechanical power also practically constant and broadly speaking equal to all the losses at no load, i. e. at $\cos\,\varphi = 0$.

In the above it has been stated that the autosynchronous motor after running up to asynchronous speed automatically synchronises itself when the rotor is supplied with direct current. But as this is not achieved under all circumstances, (without, for instance, increasing the magnetising current) it may be interesting to study this matter more closely.

Synchronising Torque of the Autosynchronous Motor.

After the autosynchronous motor has been started up and whilst the throw over switch still remains in the "start" position, i. e. downwards, (see Figs. 3 and 9) the motor still runs as an asynchronous motor with a slip "*s*" depending on the characteristics of the motor, mainly the rotor resistance, and the amount of load. When

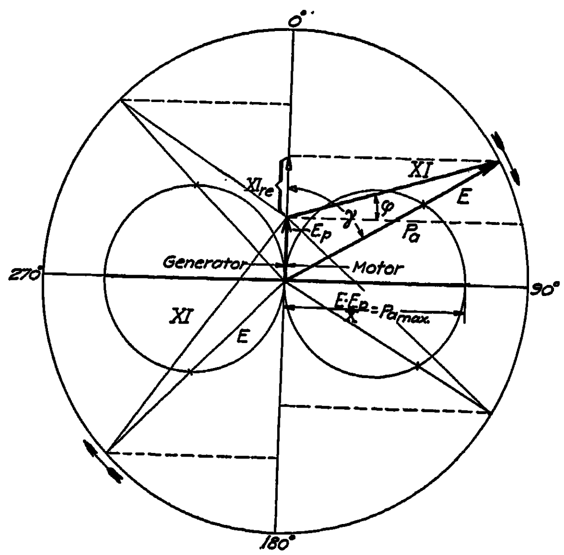


Fig. 13.

the changeover switch is reversed to the "up" position — and it is assumed that the exciter has by that time reached normal voltage — no instantaneous change is made in the motor's asynchronous characteristics as the armature winding of the exciter does not add any appreciable resistance in the rotor circuit. Before any change in speed has therefore taken place the slip of the motor is still "s" and the torque of the motor as an asynchronous one still corresponds to the temporary load. Through this changeover however a new torque condition has been added, a sychronous one, dependent upon the magnetisation of the rotor by direct current. This torque however is not constant but changes both as regards magnitude and direction according to the relative position of the fixed rotor poles and the poles in the stator created by the stator flux, and is consequently varying according to the displacement indicated by the angle γ in Fig. 10.

In Fig. 13 the vector E is assumed to rotate at a speed which is $f \cdot s$ revs per second and consequently with a period of $\frac{1}{f\,s}$ secs where f is the frequency of the primary current.

During this rotation I, I_{re}, φ, and P_a will vary as shewn in Fig. 13, which also shews that for instance I_{re} is positive above and negative below the top of E_p and that P_a is positive when the E vector cuts the lesser circle to the right and negative when cutting the corresponding circle to the left of the vertical axis of the large circle. P_a is in fact in this figure the synchronous torque M_s in question and consequently

$$M_s = M_s\,\text{max.}\,\sin\gamma = \frac{E \cdot E_p}{X} \cdot \sin\gamma$$

It is evident that this synchronous torque, immediately after the throw over switch is moved "up", will affect the speed of the motor in one way or another. If this changeover is effected when γ lies between 0 and 180° acceleration occurs and between 180° and 360° retardation occurs, and, in both cases, the smaller γ is the more effective are the acceleration and retardation in question. The most opportune moment for the changeover is when γ is 0 and the process of synchronising will be most easily achieved if the acceleration is strong enough to effect synchronism before the angle γ has passed 90°. If synchronism is only just achieved when γ lies between 90° and 180° the ability of the motor to remain in synchronism depends on whether γ is then so large as to make M_s larger or smaller than the load torque M_l.

Referring to Fig. 14 and assuming that the load torque M_l = half maximum synchronous torque i. e.

$$M_l = \frac{1}{2}\,M_s\,\text{max.} = M_s\,\text{max.} \cdot \sin 30°$$

that the changeover switch is in the "up" position when $\gamma = 0$ and that synchronism, (which means that the rotor speed is equal to the speed of the stator field, in other words, the slip $s = 0$) is achieved under the first period, the following may occur

1. Synchronism is achieved when γ is 30°; M_s is then $= M_l$ and the rotor continues to run at synchronous speed and $\gamma = 30°$.

2. Synchronism is achieved when γ lies between 30° and 150°, for instance at 90°.

The synchronous torque is then larger than the load torque and the acceleration should continue until γ is reduced to 30°. In such a case however the speed of the motor would be above synchronous speed, i. e. s negative, and the motor would then run as an asynchronous generator producing a retarding torque.

Actually however the acceleration finishes at a γ which is larger than 30° but less than 90°. The speed is then still above synchronous speed and is further reduced and finally comes below 30° but is then again increased and the whole results in a quickly dying oscillating movement of γ round about 30°. During this synchronising period the other factors, such as current, phase displacement etc. are altered as shown in the diagram in Fig. 14 for different values of γ. In cases where the motor cannot reach synchronous speed or remain at synchronous speed, the speed is continually changing as well as the current and phase displacement. If the changeover happens at $\gamma = 180°$ the slip is increased beyond normal during the first half period and the possibility

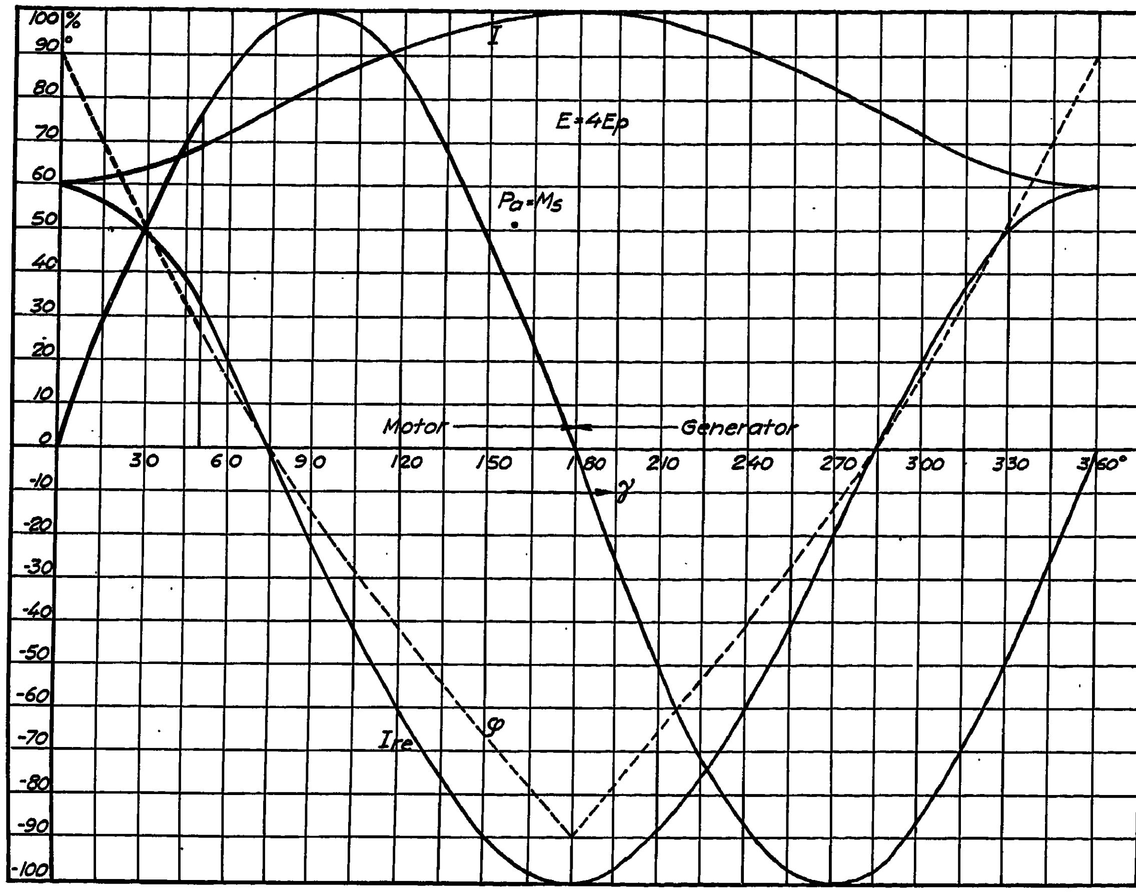


Fig. 14.

of achieving synchronism during the following half period if then of course correspondingly less. It would be practically impossible to select a suitable moment for changeover, but if an attempt is repeated a few times success should be ensured if synchronising is at all possible. As it is of course of importance to pre-determine the condition so that synchronism is possible, it is essential to closely examine the

Facts governing the synchronising ability of the motor:

The following four torques influence the rotor:

1. The load torque which is constant M_l
2. The synchronous torque $M_s = M_s$ max. sin γ
3. The asynchronous torque $M_a = k'_1 s$
4. The acceleration torque $M_{acc} = k'_2 \cdot m \dfrac{dv}{dt}$

where m is the mass of the whole rotating part and v its linear peripheral speed, both reduced to, for instance, 1 m radius.

If the speed of the primary field is v_1 (1 m radius) then:

$$v_1 - v = c \cdot \frac{d\gamma}{dt}$$

$$s = \frac{v_1 - v}{v_1} = \frac{c}{v_1} \cdot \frac{d\gamma}{dt}$$

$$M_a = k \cdot \frac{d\gamma}{dt}$$

$$\frac{dv}{dt} = - c \cdot \frac{d^2\gamma}{dt^2} \text{ and}$$

$$M_{acc} = - k_2 \cdot m \cdot \frac{d^2\gamma}{dt^2}$$

In order to obtain balance it is necessary that

$$M_s + M_a = M_l + M_{acc} \text{ and then}$$

$$M_s \text{max. sin } \gamma + k \cdot \frac{d\gamma}{dt} = M_l - k_2 \cdot m \cdot \frac{d^2\gamma}{dt^2}$$

which equation gives when solved the synchronising occurrence.

As however this equation, is difficult to solve, an approximate and more simple solution of the problem is given below.

It is assumed that the change over occurs when $\gamma = 0$ and that synchronism is reached during

the first quarter period i. e. before γ is 90°. The average value of the synchronous torque during this period would be

$$M_s \text{av.} = \frac{2}{\pi} \cdot M_s \text{max.}$$

The asynchronous torque is M_a which however during the period is reduced from M_l to 0. The average value $M_a \text{av.} = \frac{M_l}{2}$

The torque available for acceleration is consequently

$$M_{acc} = M_s \text{av.} + M_a \text{av.} - M_l$$
$$= M_s \text{av.} - \frac{M_l}{2}$$

The torque can most suitably be calculated in kg on 1 m radius.

When the synchronising operation is started the slip is s and when it finished the slip is 0, consequently the average value during this period is $s/2$. The time of this period, i. e. the time during which the acceleration shall be achieved, is consequently

$$t = \frac{1}{4\ f\ s/2} = \frac{1}{2\ f\ s} \text{ seconds}$$

the speed must be increased from

$v_1\ (1 - s)$ to v_1 and consequently

$$\triangle v = v_1 - v_1\ (1 - s) = v_1 s$$

where v_1 is the speed at 1 m radius in m per sec. We consequently get

$$M_{acc} = m \cdot \frac{\triangle v}{t} = m \cdot 2\ f v_1\ s^2 \text{ and therefore}$$

$$M_s \text{av.} - \frac{M_l}{2} = 2\ m \cdot v_1\ f\ s^2 \ldots\ldots\ldots (1)$$

If N_l represents the number of HP corresponding to the load and n the synchronous speed in revolutions per minute

$$M_l = \frac{60 \cdot 75 \cdot N_l}{2\ \pi\ n} \text{ (kgm)}$$

If E and E_p are voltage per phase and N_s max. is the maximum output of the motor as a synchronous machine in HP.

$$N_s \text{max.} = \frac{3\ E \cdot E_p}{736\ X}$$

and

$$M_s \text{av.} = \frac{2}{\pi} \cdot \frac{60 \cdot 75 \cdot N_s \text{max.}}{2\ \pi\ n} \text{ (kgm)}$$

If GD^2 is the flywheel effect of the rotating parts in kgm²

$$m = \frac{GD^2}{4 \cdot 9{,}81}$$

The above formula (1) which of course, due to the assumed conditions and simplifications made, must be regarded as only approximately correct, is however especially instructive as it clearly shows which characteristics and circumstances govern the synchronising and in what respect these facilitate or make synchronising more difficult.

From the above it is obvious, for instance, that
A large M_s max. helps synchronising and
» » M_l makes synchronising more difficult
» » $m\ (GD^2)$ makes » » »
» » v_1 » » » »
» » f » » » »
» » s » » » »

If HP is introduced insteaded of torque and kinetic energy $E\ (= \frac{1}{2}\ m\ v^2)$ the following result is achieved.

$$\frac{2}{\pi} \cdot N_s \text{max.} = \frac{N_l}{2} = \frac{4}{75} \cdot E \cdot f \cdot s^2 \ldots\ldots\ldots (2)$$

The following deductions, amongst others, can now be made:

1. It is of very great importance to keep the rotor slip as low as possible (i. e. to put as much copper as possible in the rotor winding) if the motor is to start with a big load or if the rotating parts have a large flywheel effect or, still more, if both these conditions exist.
2. Under similar conditions a large overload capacity is of importance. As this is already decided by other circumstances it is important to arrange for the possibility of increasing the same during the synchronising period by increasing the magnetisation of the rotor.
3. If the motor is started without load there is no risk whatever of failure to obtain synchronism.
4. If the flywheel capacity in the driving machinery is very large it is preferable to use a flexible coupling, or a long belt, either method of which is preferable to direct coupling.
5. All other conditions being equal, a low periodicity supply is preferable to a high one.

Practical points on their applications.

It is well known that under certain conditions the synchronous motor is liable to »hunt»: this cannot, however, take place with an autosynchronous motor as the rotor winding acts as an extremely good damper. The two parallel connected phases II and III in Fig. 5 act precisely as a damping winding whilst the whole rotor circuit is short circuited by the exciter armature which has an exceedingly low resistance.

It is true there are conditions under which an autosynchronous motor can change speed

but this phenomena is quite different to the hunting which takes place with a synchronous machine. As the armature reaction of an autosynchronous motor is relatively large, with feeble excitation the field can be neutralised by the armature reaction thus causing the motor to fall out of step. The machine does not, however, stall but continues to run as an induction motor and as such has a large overload capacity. Under these conditions an alternating current of low frequency is produced in the rotor windings which current is superimposed on the D.C produced by the exciter. At some particular instant the current induced in the rotor has the same direction as that generated by the exciter and the rotor receives an impulse tending to pull it into step. Before this has been accomplished the alternating current has changed its direction, is opposing the D.C. current from the exciter and the motor falls back to the asynchronous conditions. The rotor accordingly tends to set up a pendulum or oscillating motion which can be termed a hunting movement.

To obviate this the autosynchronous motor should be designed with an overload capacity as high as possible, which overload capacity depends upon the proportion between armature reaction and D.C. ampere-turns on the rotor, and upon the power factor at which the machine normally works: the smaller these are the greater is the maximum output of the motor. For this reason autosynchronous motors should be designed with high flux density and should have few stator turns in order to secure small armature reaction. As this procedure naturally gives a larger and more expensive machine it is usually found more desirable from the commercial point of view to design the motor for a low leading power factor. It is true that this also increases the dimensions and the price, but in addition to giving more stable running it also provides for a greater amount of power factor improvement on the system in most cases a very desirable feature.

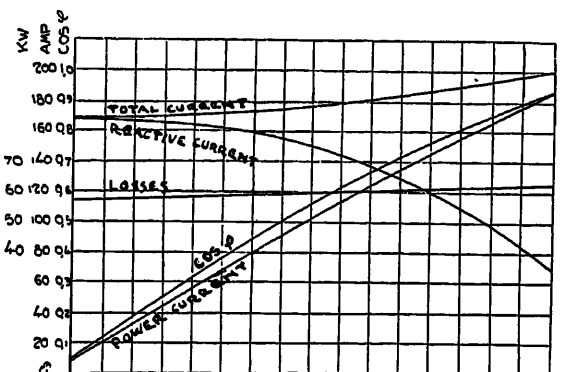


Fig 15.

When an autosynchronous motor runs with a power factor in the neighbourhood of unity it has no overload capacity: accordingly with the least increase above full load the motor falls out of step and runs as an induction motor. With lower leading power factor the overload capacity increases, and at Cos $\varphi = 0.9$ it is about 35 %. This figure is based on the assumption that the line voltage and excitation remain the same at all loads. If the excitation can be increased, this has the same effect as a lower power factor and the maximum power is consequently increased: if the line voltage falls, the overload capacity is decreased. As running conditions are seldom such that overloads cannot occur and as a possible voltage drop must be provided against, the normal overload capacity should not be less than about 35 %. Autosynchronous motors for commercial use should accordingly not be designed for a higher power factor than 0.9.

Although it will be seen that it is not expedient to design autosynchronous motors for heavy overloads, it does not matter in the least if the load is a varying one. If the load is decreased without altering the excitation, the stator current remains practically unaltered. Power current is replaced by wattless current and the leading power factor sinks (See Fig. 15). Since, as has been said before, too much of this sort of current can seldom be obtained, this is a big advantage. It is therefore not advisable to reduce the excitation to keep the power factor up even if the motor runs unloaded, but it is better to make as much use as possible of the motor as a power factor improver. The attention necessary is also, in this way, considerably decreased.

Should for any reason the maximum output of the motor as a synchronous machine be exceeded, it does not stall but as pointed out above continues to run as an asynchronous motor, and when normal conditions are restored the motor pulls into step again of its own accord and quite automatically. This synchronising can be made easier by increasing the exciting current.

The losses in an autosynchronous motor are only slightly greater than the losses in an induction motor of the same kVA capacity, the copper losses and iron losses of the stator are the same and it is only the copper losses of the rotor that are increased. Assuming the same current density in the windings, the weight of copper in the rotor of an autosynchronous motor is about $^4/_3$ times that in the rotor of an induction motor, and the rotor losses are thus approximately 33 % greater. As the regulation

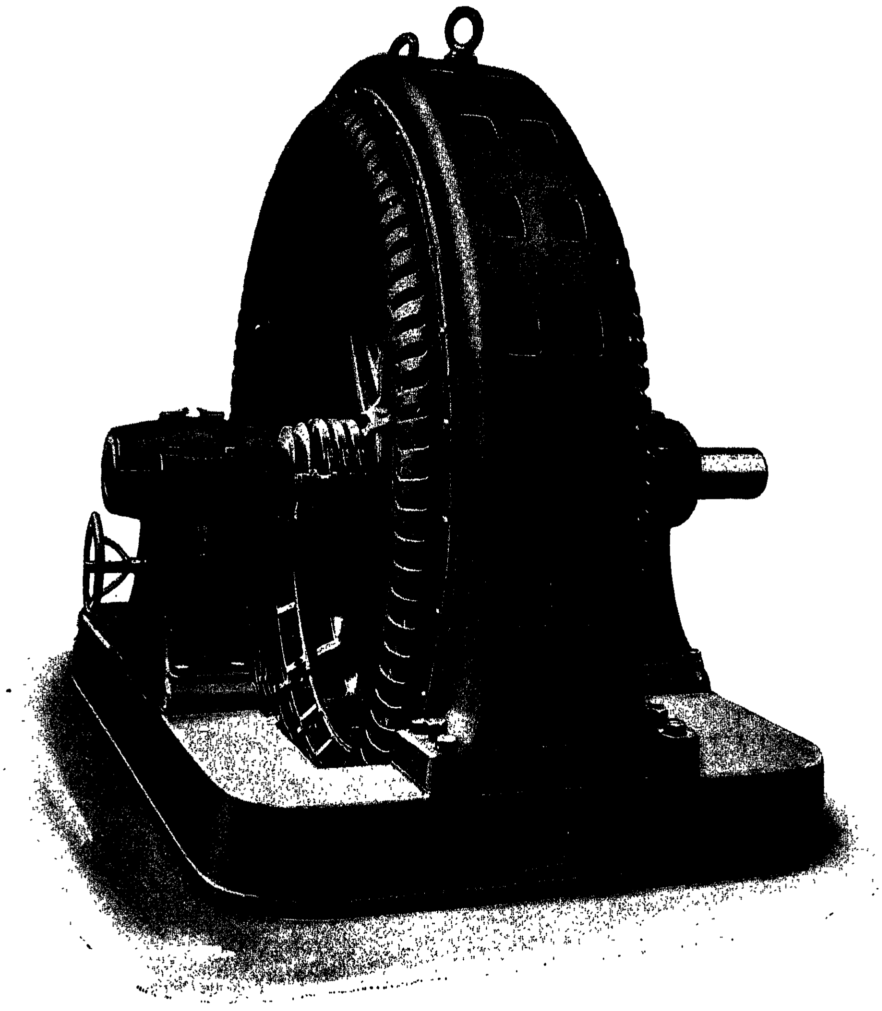


Fig. 16. Autosynchronous motor 15C0 HP, 3700 volts, 370 r. p. m., 50 cycles.

of the exciting current is done by a rheostat in the exciter shunt circuit the losses in external resistance are exceedingly small.

Autosynchronous motors can also be used as generators, but have the disadvantage of bad regulation; for example the motor to which the curves in Fig. 15 apply, the regulation at unity power factor is approximately 48 %. If, however, the load on the machine is anywhere near constant the bad regulation may not be of such great importance.

Fig. 16 shows an autosynchronous motor for 3700 volts, 1500 HP, 50 cycles, 375 r. p. m. and designed for a leading power factor of 0.9. The size of this motor is exactly the same as for an induction motor of equal output, and only differs from such a machine in having a special rotor winding and six sliprings, of which three are provided with brush lifting and short circuiting gear. (The three other sliprings are placed on the opposite side of the rotor and are therefore not visible in the illustration). The motor is connected as indicated in Fig. 9 and is accordingly started with the rotor winding Delta connected, but afterwards, when up to speed, is Star connected for the continuous current supply. The magnetising, short-circuit curves, and load point of this machine are shown in Fig. 17, whilst Fig. 15 shows the characteristic curves with different loads and constant excitation. It will be noticed that the total current falls very slightly with decreased load, power current being replaced by reactive current so that at no load this last is very nearly equal to the full load current of the motor. The apparent efficiency:

$$\left(\frac{kVA}{kVA + losses}\right)$$

is almost the same (from 94 to 95 %) at all loads.

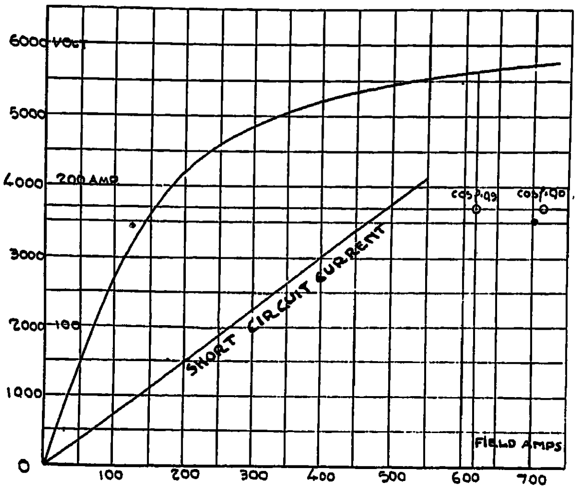


Fig. 17.

The inherent characteristic which the autosynchronous motor possesses of continuing to run as an induction motor when overloaded beyond its breaking out point as a synchronous machine is a most valuable feature under practical working conditions. When out of synchronism the motor recovers the characteristic of an ordinary induction motor with its heavy overload torque, and in spite of a low frequency alternating current being superimposed on the D.C. exciter armature there is no tendency for the latter to spark at the brushes as the RMS value of the resultant current is less than the full rated output as a D.C. machine. On account of the conditions obtaining the current circulating through the exciter armature windings gives rise to a fluctuating torque about ten times larger than the normal torque in the exciter due to the swinging when the machine falls out of step. Special precautions are therefore taken in designing the exciter to guard against mechanical or electrical damage brought about by the necessarily severe stresses which come into play under the conditions mentioned above.

Autosynchronous machines are built in numerous sizes, the general demand being between the limits of 100 HP and 1500 HP. At the Waterworks of Edmonton Corporation, Canada, two autosynchronous motors were installed each having an output of 850 BHP at 900 r. p. m.: they were designed for a leading power factor of 0.8 when working on a threephase, 2200 volt,

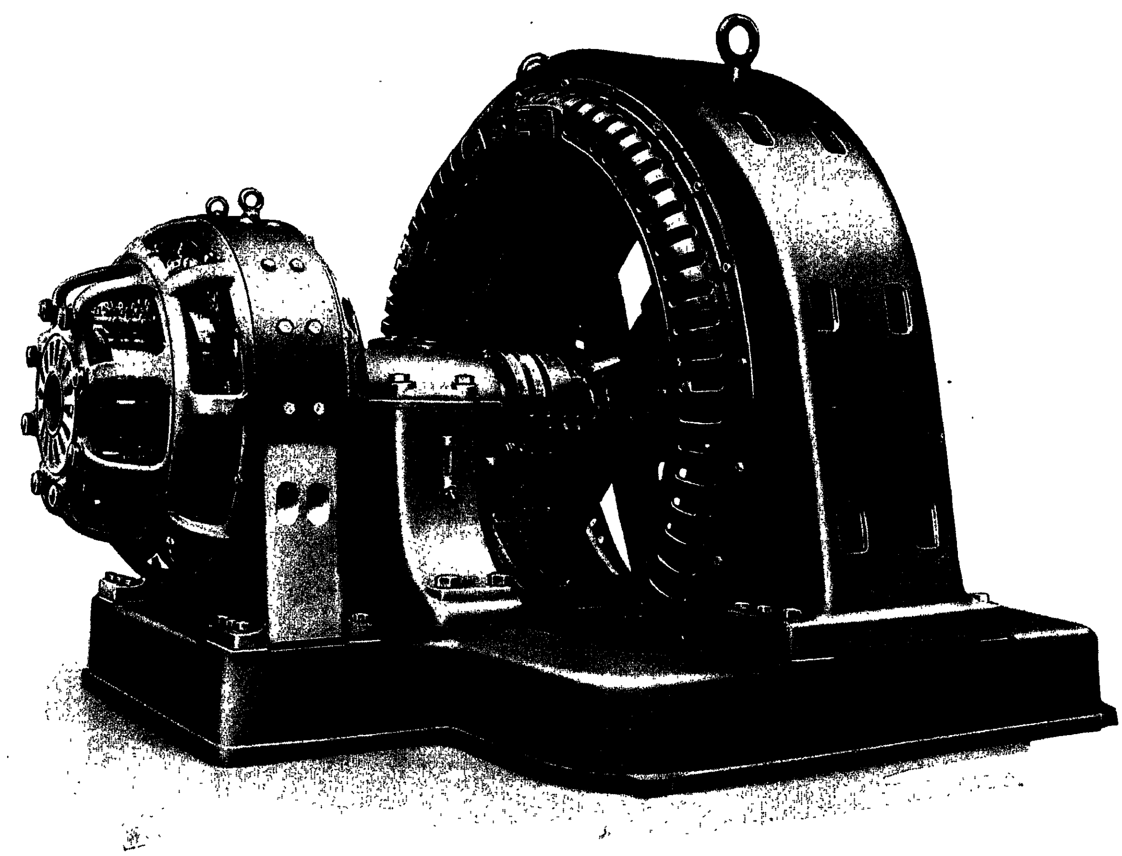


Fig. 18. Autosynchronous motor 450 HP, 3000 volts, 167 r. p. m., 50 cycles.

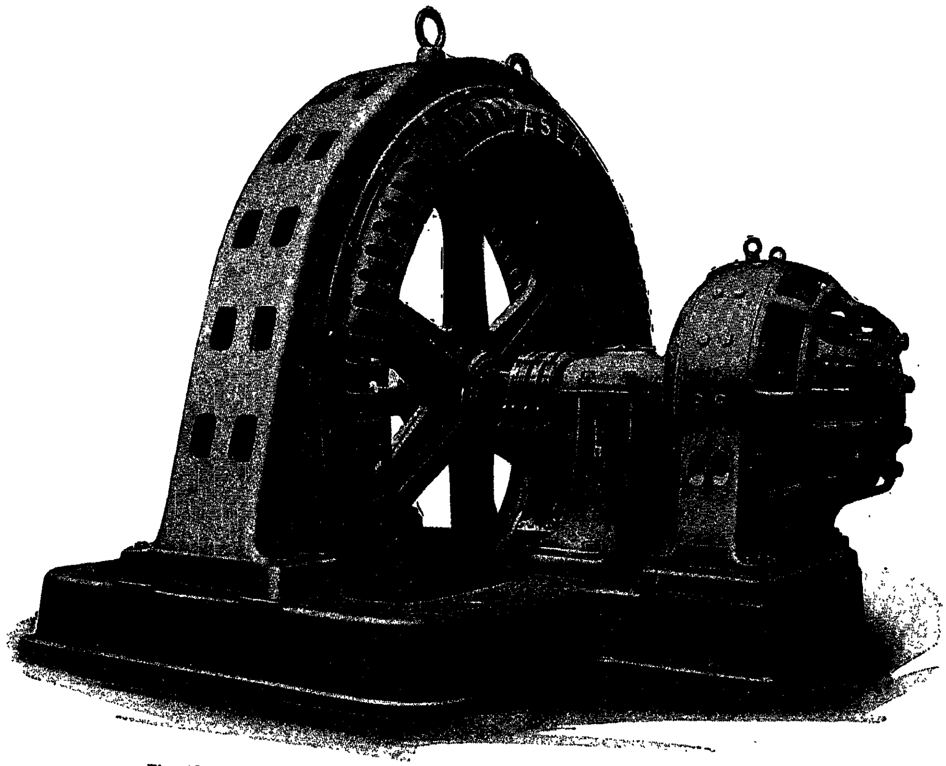


Fig. 19. Autosynchronous motor 450 HP, 3000 volts, 167 r. p. m., 50 cycles.

60 cycles circuit. Under these conditions the guaranteed efficiencies were:

Full load	*3/4 load*	*1/2 load*
93 %	91.7 %	88 %

The efficiencies ascertained on test including the losses in the exciter were:

Full load	*3/4 load*	*1/2 load*
94.5 %	93.6 %	91.9 %

Running as a synchronous motor with excitation corresponding to leading power factor 0.8, the motor could stand an overload up to 1100 HP when it pulled out of step, continued to run as an ordinary induction motor and as such developed a maximum overload up to 2500 HP. When the load was again reduced to its normal value the motor automatically pulled into step and continued to run in synchronism. The regulation of the excitation was obtained by shifting the brushes on the exciter which in this case was wound as a series machine. In this manner resistance losses in the field circuit or in the main circuit of the exciter are avoided. The exciters selected for these machines were of ample dimensions and by over-exciting the field the overload as a synchronous machine could be increased to 1400 HP without the machine falling out of step.

Motors of this description are particularly well suited for driving fans and air compressors in Collieries. Although in the case of Air Compressors the load fluctuates at frequent intervals from full load to 10 % or 15 % of full load, the leading component of the current supplied by the motor is available in spite of these load variations.

In applying this class of machine for power factor correction it should be remembered that the magnitude of the component of leading or lagging current and the watt component (in other words the total current), stand in very different proportion to each other at different values of the power factor. The wattless component and the resultant component can be expressed in kVA at various power factors on the assumption that the watt component remains constant. It will be understood that a much larger leading component is required to correct the power factor from 0.9 to 1.0 than is required from 0.8 to 0.9 or from 0.7 to 0.8. It will also be noted that the resultant output in kVA exceeds the watt component by only about 10 % at power factor 0.9, but increases very rapidly at lower power factors. The size of the motor and consequently the cost, depends upon its kVA rating and from what is said above it will be clear that in general the best plan is to make use of autosynchronous

motors for leading power factors not less than 0.7. (Induction motors designed for the same output would for moderate size machines have a lagging power factor of about 0.85.) If for the autosynchronous motor we select a leading power factor of 0.75 the machine would be roughly 12 % larger and consequently more expensive. The cost of the exciter which is quite an important item further adds to the price, as does also the special design of the machine which is required to obtain the synchronous feature whilst retaining the characteristics of the induction type. To roughly estimate the amount of correction obtainable by a given motor, it might be an advantage to remember that at a leading power factor of 0.7 the leading component of current produced expressed in kVA is denoted by the same figure which gives the output of the motor in kW. A 650 HP autosynchronous motor with an output of 480 kW would consequently at 0.7 power factor give a leading component of 480 kVA and would reduce the total lagging component of the system by this amount. If the power factor is larger than 0.7 the leading component decreases and is easily obtained by calculation or by the graphic method.

The trouble arising from a poor power factor is the overloading of transformers and feeders, due to the excessive lagging currents; or more frequently, particularly in Colliery installations or in power plants which have a large number of intermittently working motors with fluctuating loads, to the current carrying capacity of the generators to such an extent that it becomes impossible to utilise the full capacity of the prime mover whether turbine or steam engine. In such cases the installation of autosynchronous motors of suitable size may save a large amount of money, in spite of the fact that they are 25 % — 40 % dearer than the ordinary induction motor. To illustrate this by an example, assume that the load on a given power station is 1000 kW

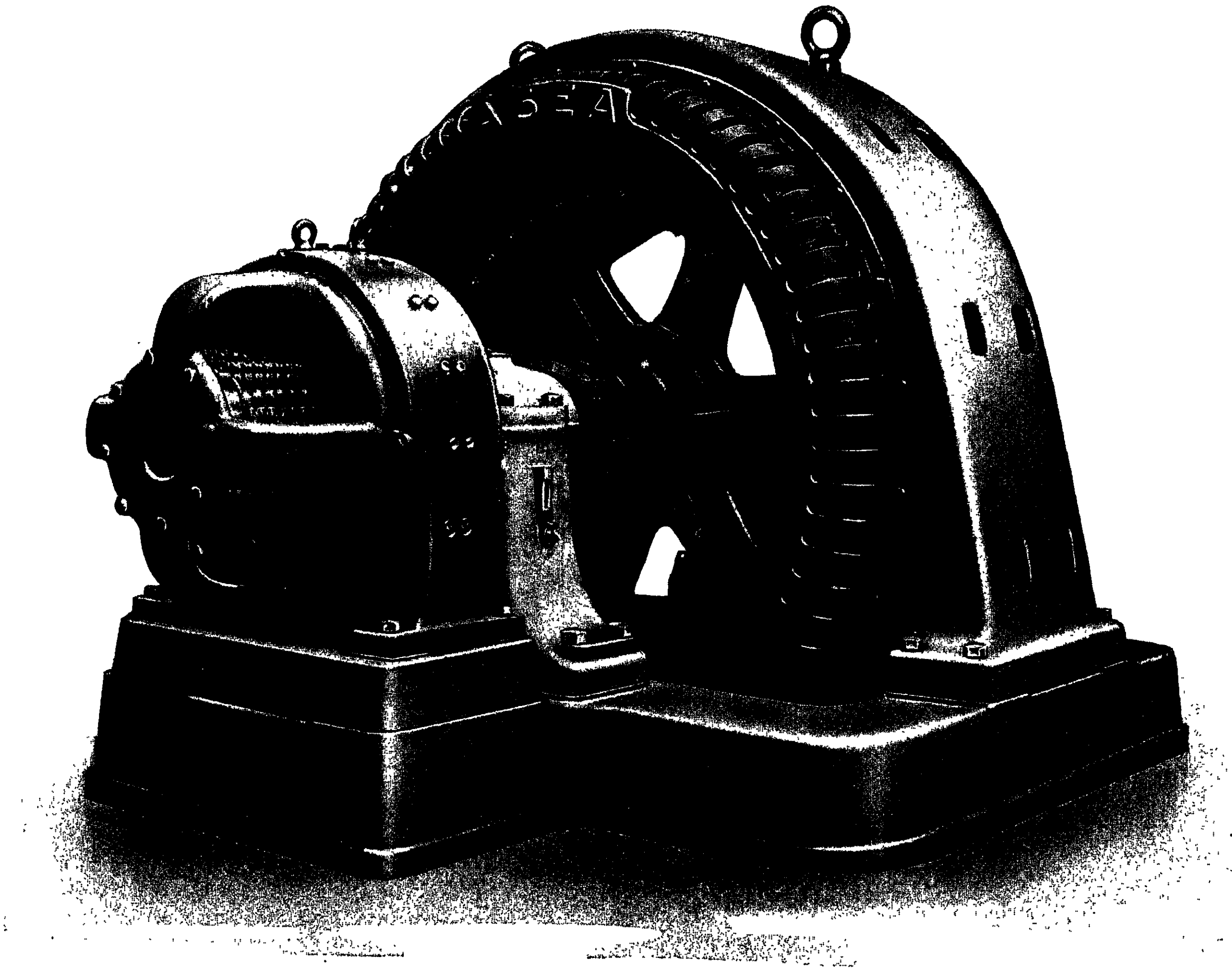


Fig. 20. Autosynchronous motor, 700 HP, 5750 volts, 375 r. p. m., 50 cycles.

at a power factor of 0.6 or 1670 kVA. It is proposed to add to this power station a further load of 500 kW. If this load consists of ordinary induction motors with a power factor of 0.8, the resultant load after the addition would be 2295 kVA with a power factor of 0.655. If, on the other hand, autosynchronous motors with a leading power factor of 0.7 are used, the resultant load on the power station would be 1700 kVA, with a power factor of 0.88. In other words, this load could be added in autosynchronous motors without appreciably increasing the kVA output of the station and if, as is often the case in generating stations installed six years or more ago, the same plant is sufficient to carry the increased load, the existing plant could carry the increased output if autosynchronous motors are employed, whereas with induction motors an extension of the power station would be unavoidable.

Figs. 18, 19, 20 and 21 show the general appearance of Autosynchronous Motors, their leading characteristics being given in the respective titles of the illustrations.

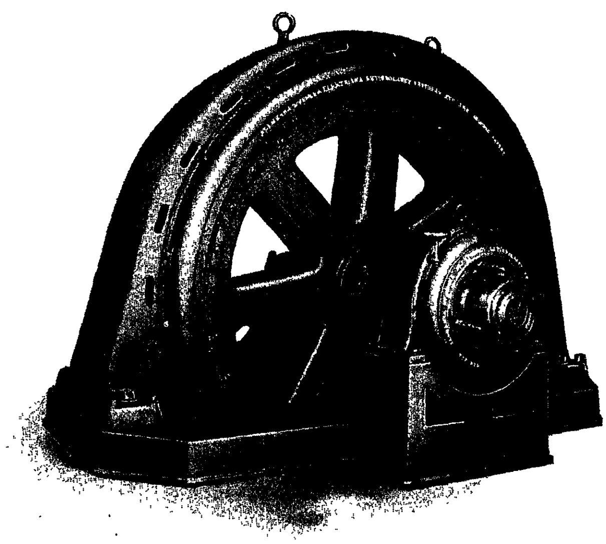


Fig. 21. Autosynchronous motor 500 HP, 490 volts, 225 r. p. m., 60 cycles.

Västerås, Sweden, X; 1923, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

INDEX 1924

PUBLISHED BY

ALLMANNA SVENSKA
ELEKTRISKA A.B.
VESTERAS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

INDEX

AS
EA

ASEA-JOURNAL

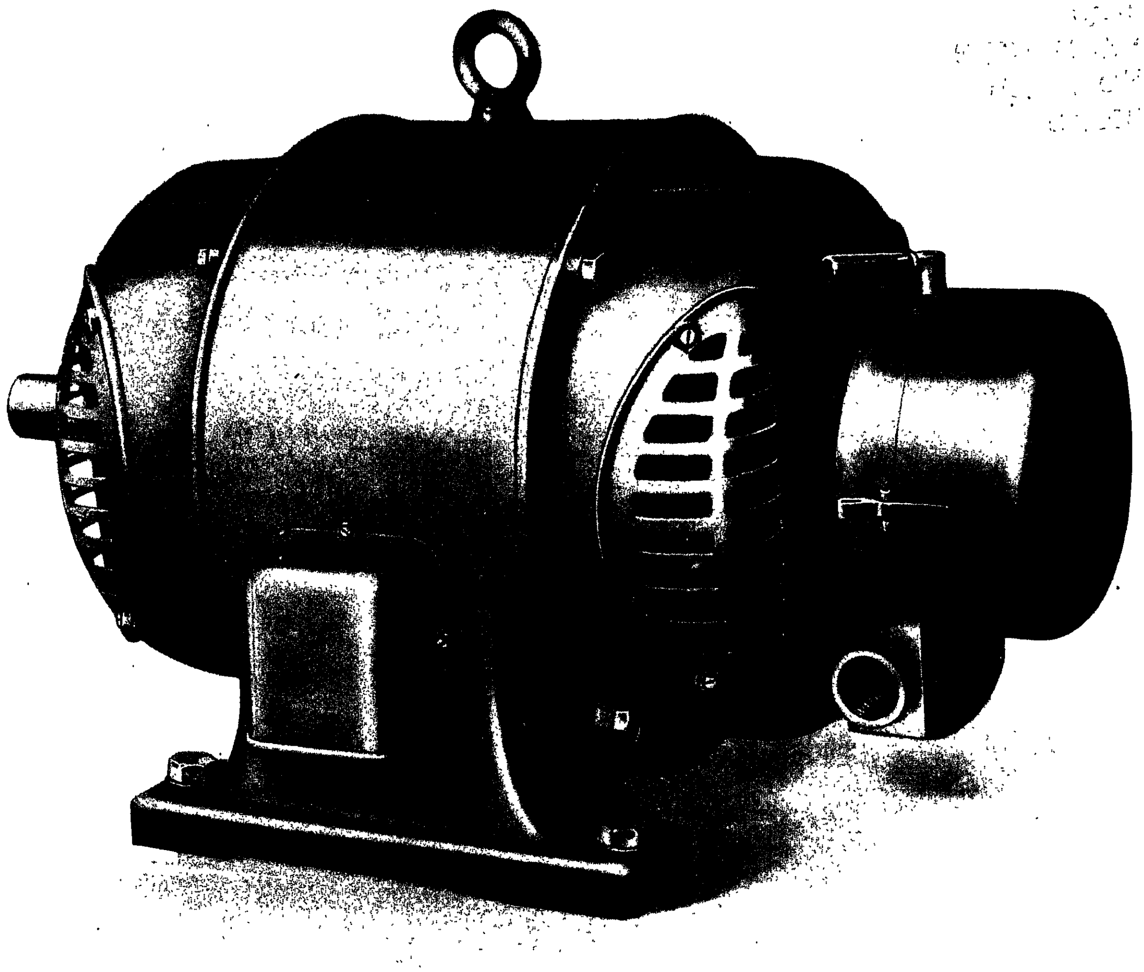
ALLMÄNNA SVENSKA
ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

APRIL

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesteras, Sweden.
Permission is given to reprint articles or extracts from this journal,
on condition that the name — Asea-Journal — is clearly stated.

1924



Three-phase motor type MK, form B, with slipring rotor.

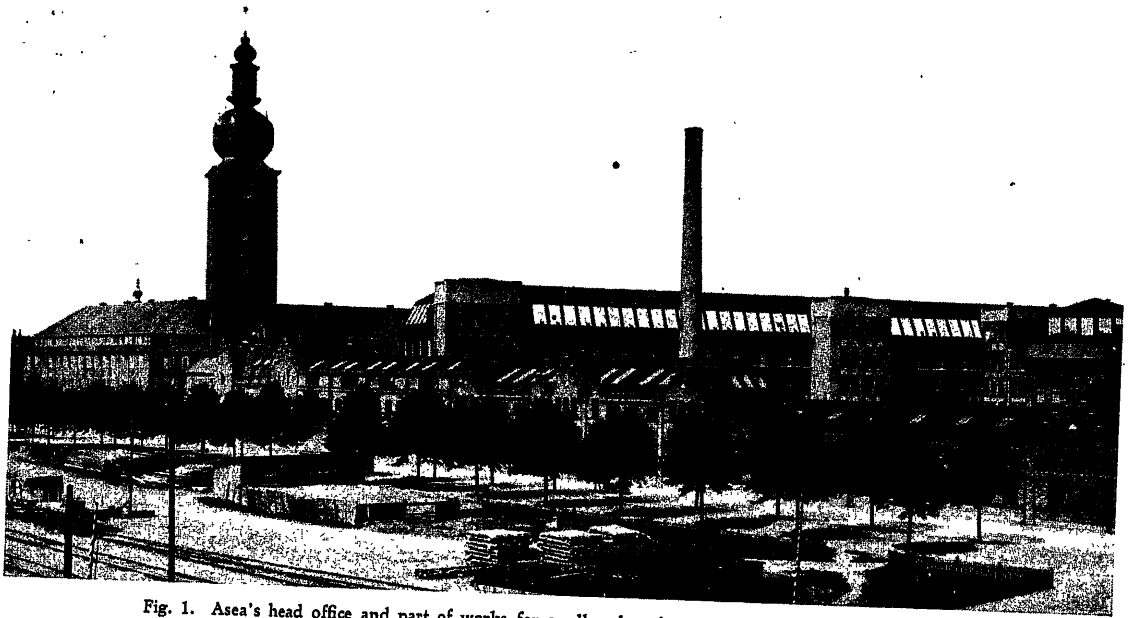


Fig. 1. Asea's head office and part of works for small and medium sized machines, Vesteras, Sweden.

ASEA
ALLMANNA SVENSKA ELEKTRISKA AKTIEBOLAGET
OR IN ENGLISH
THE SWEDISH GENERAL ELECTRIC LIMITED

was formed as long ago as 1883, and was based to a great extent upon the epoch making discoveries in the applications of electricity by the noted Swedish Engineer Jonas Wenström. The capital of the company was only Kr. 84.000 (about £ 5.000) and small premises were rented in the town of Arboga, Sweden to serve as workshops. By comparison with the present concern, the new company could hardly have enjoyed a more modest existance at the commencement. During the first two years the output was only fifteen machines, and the largest built was of about 20 HP. Although the future of this young undertaking many times looked very gloomy, a state of affairs to which the unfavourable foreign exchange contributed not a little, still the company won increasing confidence and continually forged ahead, so that time after time additions had to be made to the rented workshops. The size of the plant, and also of the machines, increased and in the year 1890 the first machines of 100 HP was turned out.

In 1890 a reorganisation took place; the share capital was increased to Kr. 500.000 (£ 30.000), and it was decided to transfer the scene of operations to the town of Vesteras, which since that time has become the hub of the electrical industry in Sweden.

Work in the new shops was soon under way. In the first year 100 machines totalling 900 kW, and in the second year 85 totalling 1.500 kW, were manufactured.

The facilities existing at that time for the manufacture of large machines are not however comparable with those which can be commanded at the present day, while, owing to the general developement of the waterfalls, the demand for larger, and still larger units, became daily more insistant.

To meet this demand, and also to ensure that there should be no handicap to its manufactures ranking among the very best, the company determined to possess shops of the most up to date character. A large part of the older works buildings were accordingly demolished and more

Fig. 2. Part of Asea's works for small and medium sized machines and foundries in Vesteras.

modern shops erected in their stead. As a result it can be said with conviction that the company's present chief factory, used for the production of small and medium sized machines, the so called 'Mimer Works', is one of the most up to date which can be found in the whole of Europe.

The shops for the production of large electrical machines have been about quadrupled since the beginning of 1900.

In the buildings thus newly acquired, the most modern and timesaving machine tools were installed at the outset. Particular care has been taken to see that these tools are kept in perfect order and replaced by newer patterns as soon as they become obsolete. Automatic and semi-automatic machines are used to as great and extent as possible to economise skilled manual labour. A secondar result of this policy has been a considerably increased output.

The resources of the mechanical departments have also been increased to a great extent. There has been a continual increase in the use of electric power in different systems of transport, such as trams, railways, also cranes, lifts, traverses, ships winches, etc. Partly to insure itself in respect to deliveries of various necessary adjuncts to its electrical manufactures, and partly to increase its all-round capability, Asea has taken up the production of such material to a considerable extent.

In order to be as far as possible independent with regard to the supply of the manifold insulating materials which are used in the electrical industry, the quality of which is of paramount importance to the reliability of the finished product, the Company started its own insulation works.

It had meanwhile become clear, for many good reasons, that the company's extending engineering work and yearly increasing parallel activities could no longer be adequately dealt with in Vesteras alone.

The manufacture of transformers and apparatus was accordingly transferred in 1916, to extensive and specially modernised shops, situated in the town of Ludvika, lying about seventy miles to the north of Vesteras.

Not only does Asea own these electrical shops in Vesteras and Ludvika, but has also absorbed one of Sweden's most important iron-works with the mines and blastfurnaces appertaining thereto, and which, by the side of their former manufacturing lines, now supply the special material covering the wide field of Asea's requirements. Thus the safe arrival of supplies of another important raw material of dependable quality has been secured — a factor naturally of considerable import to the quality of the finished product. All material, as it is received for use, becomes the object of searching examination in the Asea laboratories.

During the years 1916—1919 the company's great administrative building was erected in Vesteras, consisting of five floors, of which four

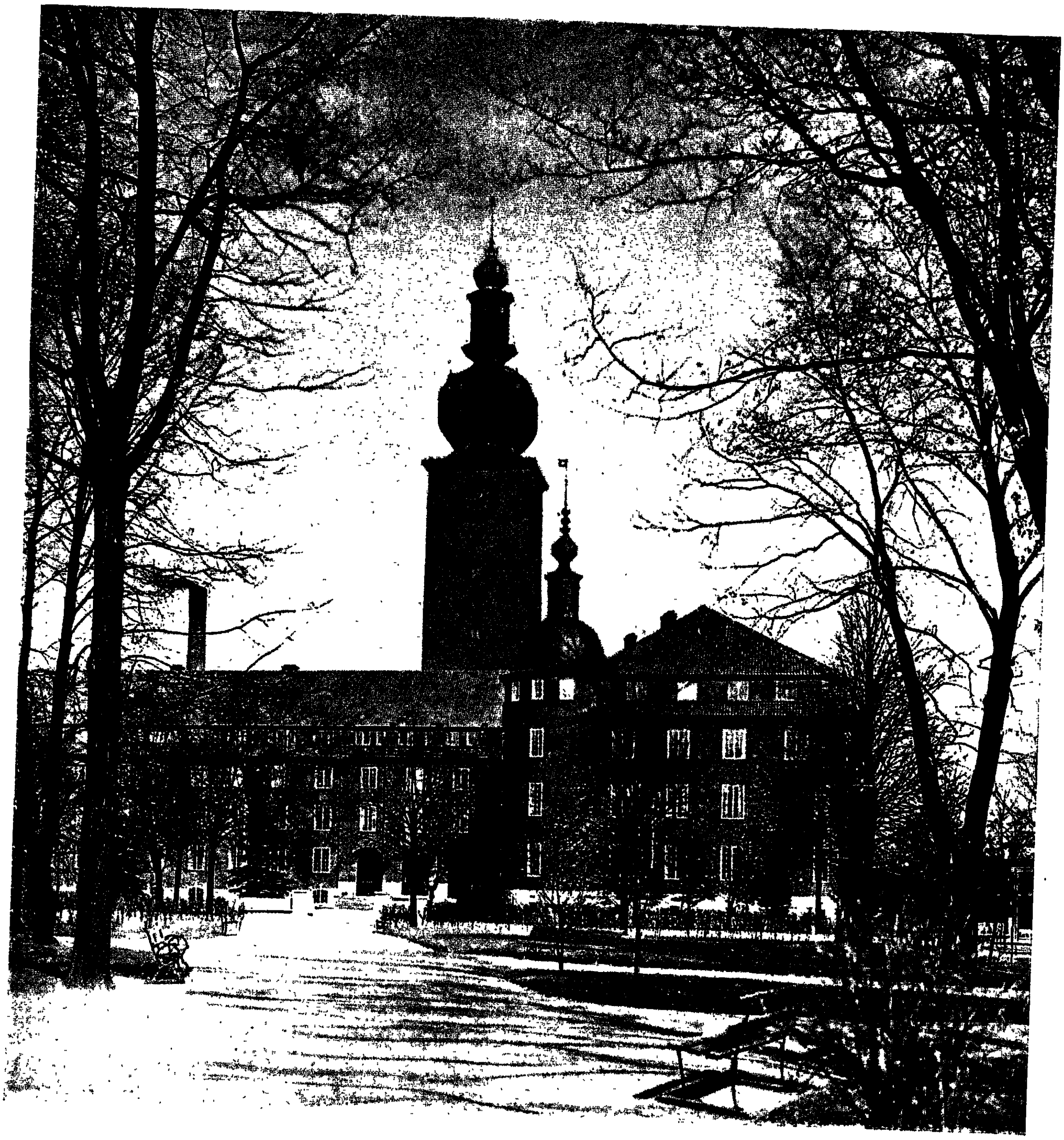


Fig. 3. The head office in Vesteras.

are above ground, with a semi-basement below. This building provides a total floor space of 14.500 square yards. Besides accomodation for the offices in the upper stories, the basement houses the records, and a museum, in which are preserved specimens of the older machine types etc., — a collection which is already of the greatest interest.

From the production of electric motors, which was inititally undertaken, Asea's manufactures have gradually developed until they now embrace practically every article on the electrical market, from switches and fuses up to giant generators of 25.000 kVA, and plants for hundreds of thousands of horsepower. Asea's main activity is, nevertheless, the making of electrical machines, and the supply of electric plant of all kinds. Without going into too great detail it is proposed in the following pages to give some particulars, which it is hoped will be of interest, regarding the Asea manufactures. For the sake of lucidity we shall follow the different machine types and begin with the generators.

Asea constructs generators for direct coupling

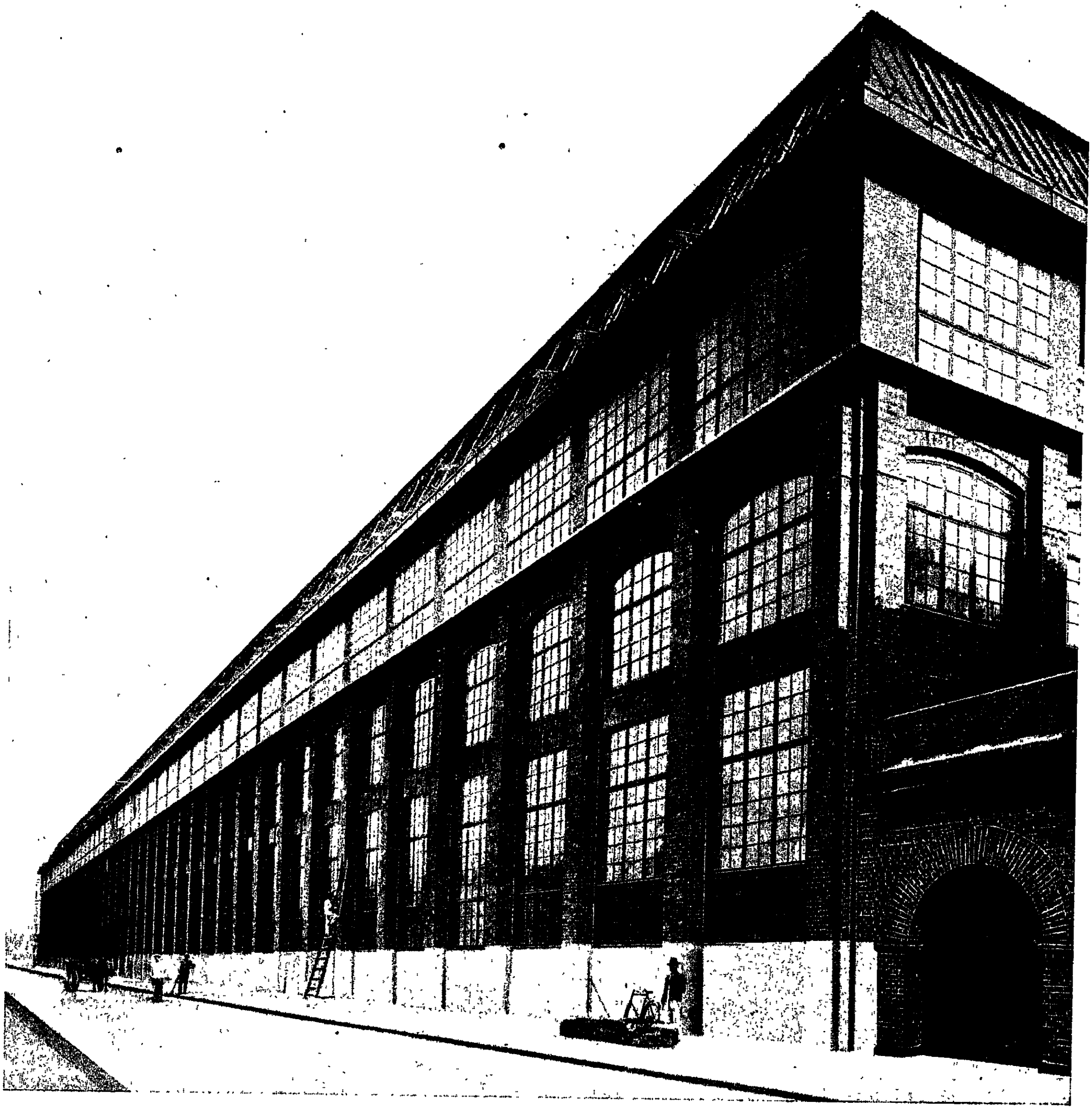


Fig. 4. The »Mimer» works for small and medium sized machines.

to every kind of prime-mover, from the slowest running water turbine to the fastest steam turbine. The smallest of these are continuous current generators of 25 kW, and the largest water turbine driven three-phase generators of 30.000 HP and over. The first machines made by Asea were continuous current generators and these have always been an important branch of the work carried on. A pioneer, in some respects, in this quarter, with its first machines Asea has steadily maintained this manufacture on a high level, and now constructs standardised machines in sizes from 1.000 kW at 500 RPM down to 0.25 kW, 2.200 RPM and special machines of every common size in addition.

It is, however, not in general of DC machines that one thinks when one speaks of Asea generators, but rather of AC generators. The construction of this class of machine is also one of Asea's oldest specialities. Based, like the DC machine manufacture, upon a patent of Wenström, they had as long ago as 1890 taken a significant place beside the other branches of construction and with the general adoption of

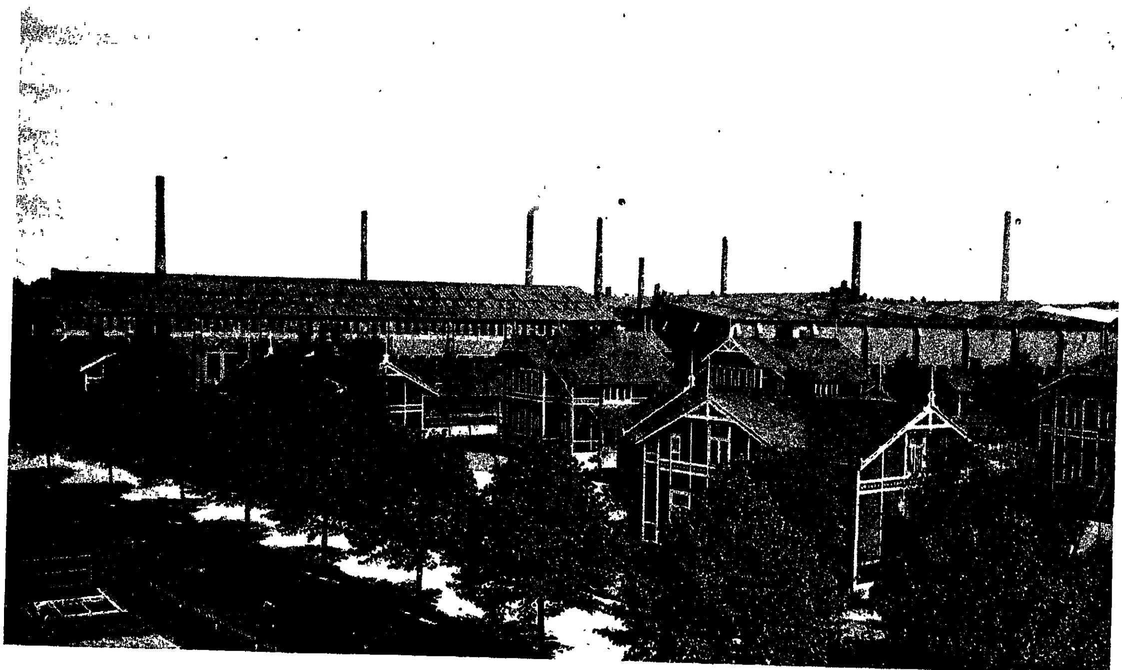


Fig. 5. Asea's factory for large machines.

the three-phase system soon became the centre of attention. Although, as has been said above, generators are made for coupling direct to all kinds of driving machinery, still, on account of the characteristics of the countries in which Asea has found its most important markets, the water turbine driven generators have been not only the largest in size but also the most numerous. For installations in Sweden alone Asea has supplied about 80 % of the AC generators which have been installed, totalling upwards of 1.150.000 HP. The standardised designs for

Fig. 6. Asea's mechanical works.

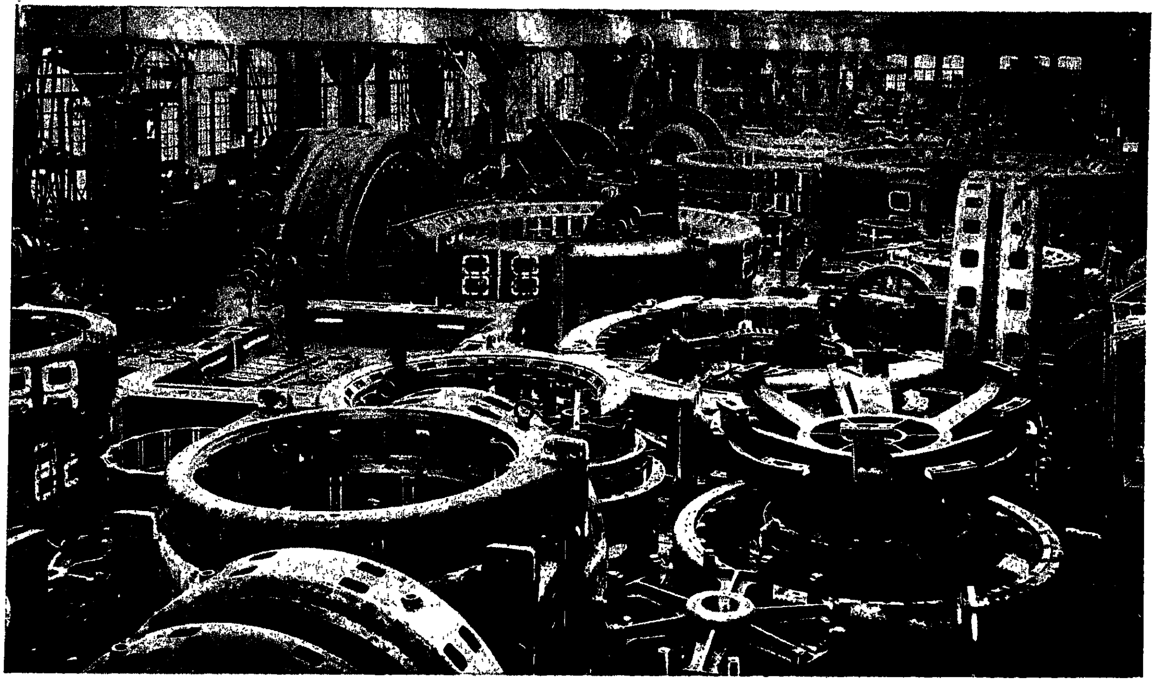


Fig. 7. Interior of one of the workshops in Asea's factory for large machines.

these machines, now embrace all sizes, from 7.500 kVA at 150 RPM down to 3.5 kVA at 1.500 RPM and 50 cycles. From between these limits it is possible to select the most suitable size for any ordinary installation. General attention was soon drawn to Asea's generators, chiefly on account of the giant machines which were from time to time constructed concurrently with the standard units.

Also Asea carried off the world's record for large generators in 1907, with four machines each of 10.500 kVA for Svaelgfos power station

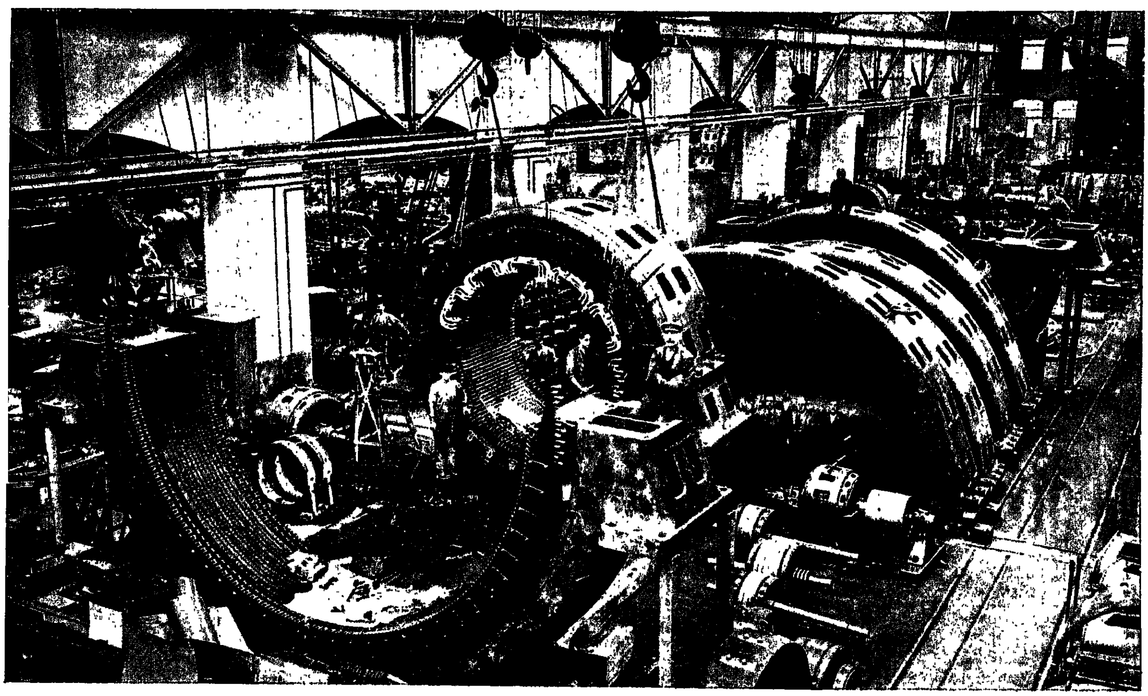


Fig. 8. Some large generators under construction.

Fig. 9. The mechanical department in Asea's factory for small machines.

in Norway, and repeated this achievement in 1915 with six three-phase generators for the Rjukanfos station, each of 18.900 kVA.

Later noteworthy examples of generator manufacture are three machines, two for 22.000 kVA and one for 24.000 kVA supplied to the Norwegian Government for the power station at Glomfjord. All these big machines are driven by water turbines. A large number of power stations in all parts of the world are equipped with Asea generators.

An important link in the chain between machines for generating electricity and those for making use of it is supplied by the transformer. Asea's production of this apparatus has always kept pace with the other manufactures. Standard transformers are built in all sizes from 11 to 5.000 kVA at 50 cycles and to 3.000 kVA

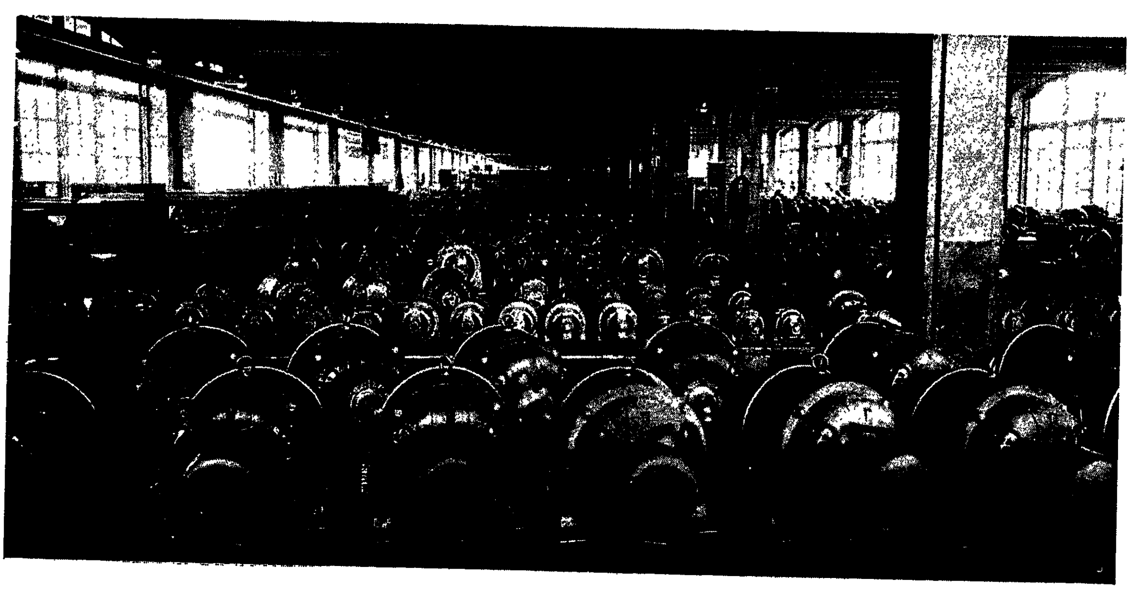


Fig. 10. Testing room for small motors.

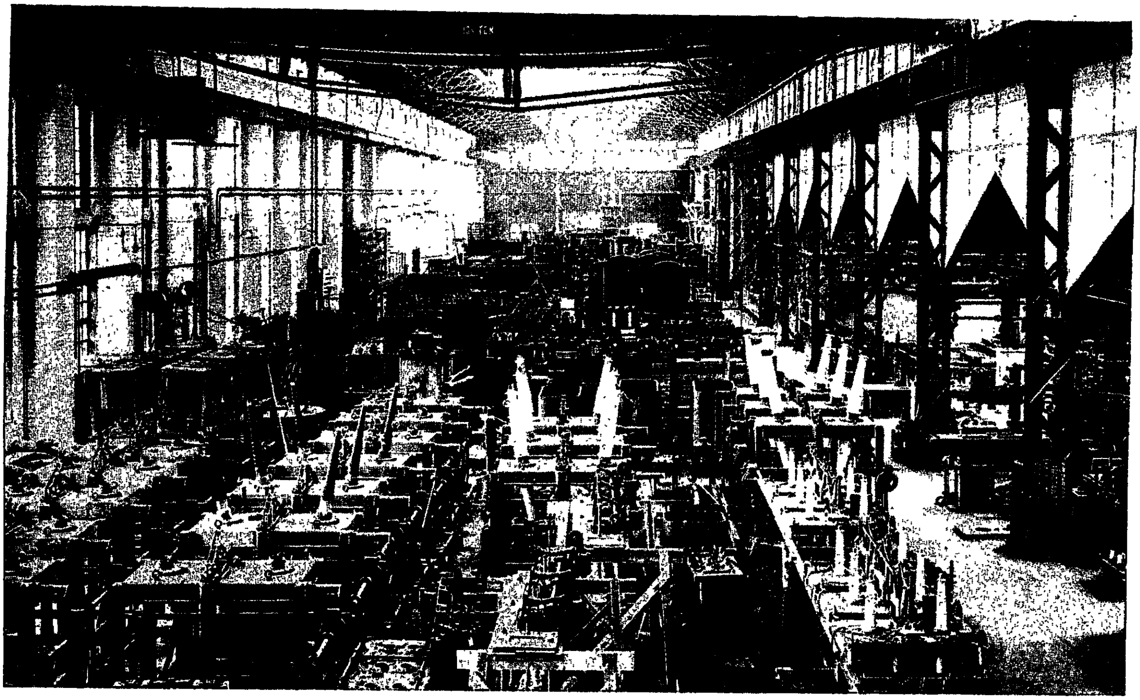


Fig. 11. Interior of one of the workshops in Asea's factories at Ludvika.

at 25 cycles for all common voltages, but, at the same time, a large number of transformers have been made for special service, transformers for use with electric furnaces being especially worthy of mention. Of other kinds also, a number of particularly interesting examples have been designed and built. Among these are two core type three-phase transformers for outdoor use each of 20.000 kVA and $\frac{126.000}{109.000}/70.000$ volts supplied to the Swedish State Waterfalls Board.

As in the case of generators, the manufacture of motors was at first confined to DC machines and Asea's No. 1 machine was a little DC motor. Now, these are built in standard sizes, from 0.25 HP at 1.500 RPM up to 1.400 HP at 500 RPM, besides special motors of all sizes. Of late years great attention has been given to large mine-

Fig. 12. Manufacturing railway and tramcar bodies at Asea's mechanical works.

Fig. 13. Some completed transformers ready for despatch from S.G.E.'s transformer works at Walthamstow, London.

hoist equipments consisting of motor-generator sets and big, slow-running, reversible winding motors, and also plants designed on the same principle for the electric drive of reversible rolling mills. An example of this last type of motor which is worthy of special note is one supplied to Domnarvet Iron Works, which is capable of a maximum output of 9.200 HP at 60—150 RPM. The construction of AC motors was taken up at the same time as generators for the same system, and at the present time synchronous motors in sizes from 0.25 HP at 3.000 RPM to 2.500 HP at 250 RPM for 50 cycles and from 0.25 HP at 1.500 RPM to 2.500 HP at 250 RPM for 25 cycles, are covered by the standard range. Within these limits there is a very large number of standard designs to choose from and in the case of the medium and small sizes a stock is maintained of the most commonly demanded Asea types. Naturally, in this case also, the standard series does not nearly cover the output; but Asea manufactures these machines for every required size and speed which it is possible to supply. A great number of very large three-phase motors have recently been turned out. The largest in Sweden is an induction motor which is continuously rated for 4.300 HP at 295 RPM, 25 cycles and 3.000 volts. Synchronous motors have also been supplied in great numbers and for large horsepowers. The two largest are each of 5.000 kVA, 375 RPM, 10.000 volts, the one for 25, and the other for 50 cycles. The difficulty of starting synchronous motors has greatly militated against their general adoption. Asea builds these self-starting synchronous motors, at the present time, however, in medium sizes, which are suitable for installations where they can be started light or with only a small load.

One of the chief advantages which the synchronous motor has over the induction motor: the property of being able to be used for power-factor correction, is possessed also by the autosynchronous motor, which was patented by Asea in 1900. This ingenious invention makes possible a combination of the synchronous motor's power-factor correcting attributes with the induction motor's property of starting against torque, which can go up to several times normal without taking a larger current than that corresponding to the load. On account of these characteristics the autosynchronous motor has been very largely used, and Asea has delivered these machines to all parts of the world.

Induction motors cannot be used with advan-

Fig. 14. The winding department in S.G.E.'s factory at Walthamstow, London.

tage when a large amount of speed regulation is required. If one excludes cascade coupling, and pole-changing devices, by which means different speeds can certainly be advantageously used, and which have been used in a number of special cases; as for rolling mill drives etc., the ordinary three-phase motor does not lend itself to speed regulation. To enable machinery to be driven at variable speeds within wide limits when a three phase supply is available Asea's three-phase commutator motors are used, which are built for use on three-phase circuits in sizes from 3 HP at 500 RPM to 75 HP at 700 RPM. The speed of these machines can be continuously regulated in the ratio of 1: 3, practically without increase in losses.

For electric railway work, single-phase commutator motors are built for all sizes met with, the largest, so far, being the 1.000 HP motors furnished for the locomotives of the Swedish State Railway in Lappland, the Riksgräns Railway.

For running all the different types of machines which have been described above, it is natural that an almost infinite variety of switchgear and instruments are required and no branch of this work is unknown in the Asea shops. All kinds of switchboards with their instruments and apparatus are continually going through.

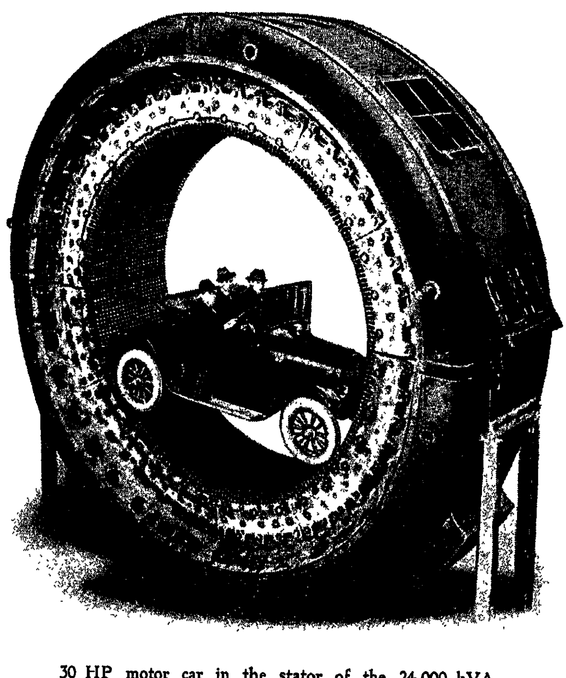
Of the immense variety of apparatus, every example of which is of importance in its own class, the oil switches are of particular interest. They are made in all sizes and for the most varied breaking capacities and working voltages. Attention may well be drawn, in this connection, to the excellent examples of this class of work supplied for the Untra power station in Sweden. These oil switches have a breaking capacity of 300.000 kVA and the working voltage is 100.000.

Turning now from the machines themselves to their sphere of action, it is perhaps in the wide domain of railway electrification that the greatest interest will be felt.

Asea, by the electrification of the Riksgräns Railway, as well as a number of other lines, and many tramways in Sweden, Norway, Denmark and Finland, has demonstrated its ability to supply complete installations, for the most diverse traffic considerations, and to furnish them with the most suitable electrical machinery. The most favourable results have been obtained during the 10 years that the Riksgräns Railway has been running, very far exceeding the requirements of a very difficult specification, and the time the line has been in use has proved the suitability and wearing qualities of the electrical equipment under the most varying running conditions.

Of the many other directions in which Asea has carried out much important and successful pioneer work, e. g. in the questions of electrification of iron works, or its contributions to the solution of electric drive problems in the timber, paper, sugar, and textile industries etc., space will not allow of more than mention.

Side by side with the advancement effected in the quality and quantity of the manufactures, a wide extension of the company's selling organisation has gradually been undertaken. At the present time Asea has offices, subsidiary companies, and agents, in nearly all European countries, and in every other land where any outlet for the companies goods is to be anticipated. The subsidiary companies in Norway, England and Russia possess factories of their own which work to Asea designs exclusivly.



30 HP motor car in the stator of the 24.000 kVA three-phase generator for the Norwegian Government power station at Glomfjord.

TYPE MK MOTORS.

On the front page of this issue an induction motor of our new design, type MK, is introduced to our readers. This new motor type covers normal three-phase induction motors from $^1/_4$ to 80 HP. The most characteristical feature for this new motor being the method of protection, which makes it possible to install the motor in practically any locality.

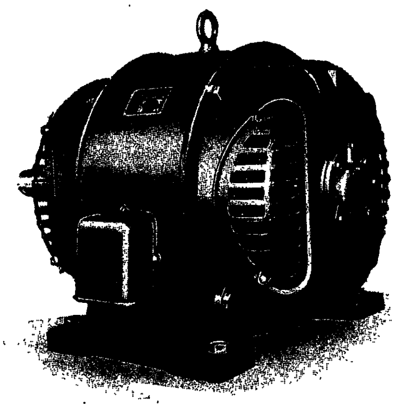


Fig. 1. Small three-phase motor type MK, form B, with squirrel cage rotor.

In the design of the MK-motor has been incorporated the whole of Asea's previous experience in induction motor designs, as well as the desires of the different customers as far as these could be amalgamated in one design.

The type MK motors are normally of the open protected type, form B (fig. 1), but it can easily be transformed into a drip-proof form E (fig. 2), pipe-ventilated form P (fig. 3), or a totally enclosed form Q (fig. 4) motor.

As the sliprings are totally enclosed outside the front bearing bracket, the motors of form B can be used in places where there is fire-risk from dust etc., as in wood-working shops, but this design has also the advantage of shortening the length of free-shaft between bearings and thus diminishing the risk of fouling between stator and rotor. For fiery mines a special slipring enclosure (fig. 5) is designed; this design will be treated later on in a special article. Vertical motors can be had in the different forms indicated above for direct coupling or for belt-drive, with or without third bearing (fig. 7).

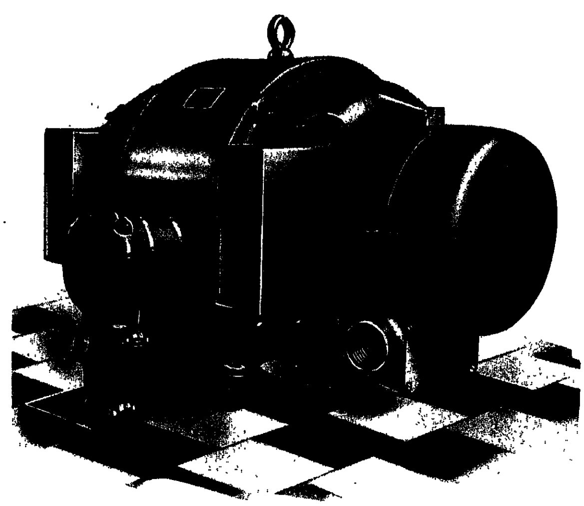


Fig. 3. Three-phase motor type MK, form P, with slipring rotor.

When designing these motors, two questions especially were studied for a long time before a final decision was made, namely: those of bearings and ventilation.

The small and medium size of three-phase motors usually gets very little care and attention, especially when installed in agricultural developements, mines, steel mills etc. As the air gap on induction motors is generally small, it is of the utmost importance to see that the bearings will not wear; if possible, even when the lubrication is not regularly inspected. We have in the ball bearing such a design which will run practically without wearing and with lubrication just sufficient to avoid rust in the balls and races. On the other hand the use of ball bearings has become very popular with the motor car and the Skefko, (Skayef) and other standard ball bearings can be had almost all over the world so that no difficulties should be encountered, should spare bearings become necessary.

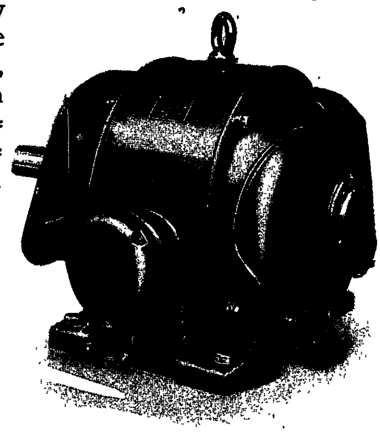


Fig. 2. Three-phase motor type MK, form E, with squirrel cage rotor.

This question was thus reduced to one of price as the manufacturing cost of a motor with ball bearings will be 8—5 % higher, dependent on size, than for a motor with babitted bushings.

Having considered the advantages of practically no wear and, therefore, no danger of rubbing between the stator and the rotor, — which accident usually gives occassion for re-winding, — the possibility of making the bearings absolutely dust-proof, as well as the advantage to the users in the reduction of friction losses, lower repair costs of bearings and less worry about lubrication, we decided to adopt ball bearings for the whole series of MK motors. Further, it was decided to make the ball bearing on the shaft-end side of the motor of such

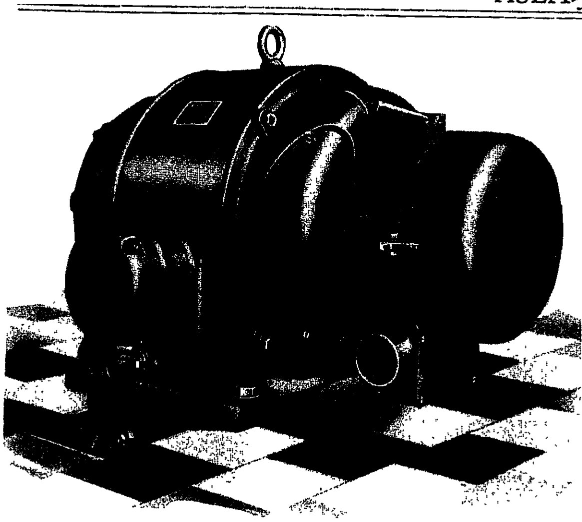


Fig. 4. Three=phase motor type MK, form Q, with slipring rotor.

dimensions as to enable it to be exchanged with a standard roller bearing, should the require=ments of the service expected of the motor necessitate such a change.

Later developements of the bearing question for electric motors have shown the advisability of this choice of design, as we note a recent decision (Sept. 1923) of the Committee on Bearings of the Association of Iron & Steel Electrical Engineers in America after a joint meeting with the Power Club (Association of American Electrical Manufacturers), to standar=dize on ball and roller bearings for steel=mill motors and to choose the dimensions of the ball bearings so as to comply with the above indicated possibility, viz: their exchange for roller bearings.

In the justification given for this decision, the above mentioned Association of Engineers points out, that only a relatively small class of users of motors do not believe in ball or roller bearings, as they only use motors for relatively easy work or else do not know the real cause of their motor failures. The majority of users either have already used ball or roller bearings or believe in them, and only wait for the stan=dardisation of the ball=bearing motor.

There are two methods for ventilating an electric motor, viz: the radial, — where the air enters in the centre of the rotor and is con=ducted through radial vents in the core through the rotor and stator to the outside, — and the axial method of ventilation, — where the di=rection of air flow is parallel with the shaft through the rotor and the stator. In this case a special fan is necessary for the air motion.

The first method is the older one and is still extensively used to=day but is specially adapted for large motors where the distance between the slots, (the thickness of the teeth), are rela=tively large. For small motors this design does not give good results, due to the narrow spaces between the slots in the rotor and in the stator, which are easily clogged up by dust and grit. Therefore, a small motor with radial ventilation ducts which just complies with the regulation concerning temperature rise when it leaves the factory, will very soon overheat in service due to the alteration of its fanning action.

The second method is the more scientific one, as the heat conductivity of a sheet iron core is more than ten times as high in the direction of the laminations as it is perpendicular to them. Further, there are no tiny holes for the air to pass out, but large canals easily cleaned from the dust that may eventually adhere to the surfaces. This accumulation will be much less if the fan, as in the type MK motor, is adap=ted to create a vacuum in the motor as soon as it is started in order to draw out all dust which has accumulated while the motor has been idle.

As an example and to illustrate the difference between the two methods, we may quote one experience made with both methods before defi=nitely adopting the axial method for the MK motors. Two open type motors of practically the same output, — one with the old radial venti=lation and the other of the axial type, — were installed in the dustiest part of our foundry, *i. e.*, the sand preparation plant and fettling shop. After eight months service the two motors were re=moved and tested, then taken apart and inspec=ted. The test showed that the first motor had an increased temperature rise of about 8° C, where=as the MK motor did not show any measurable change. An inspection of the motors showed

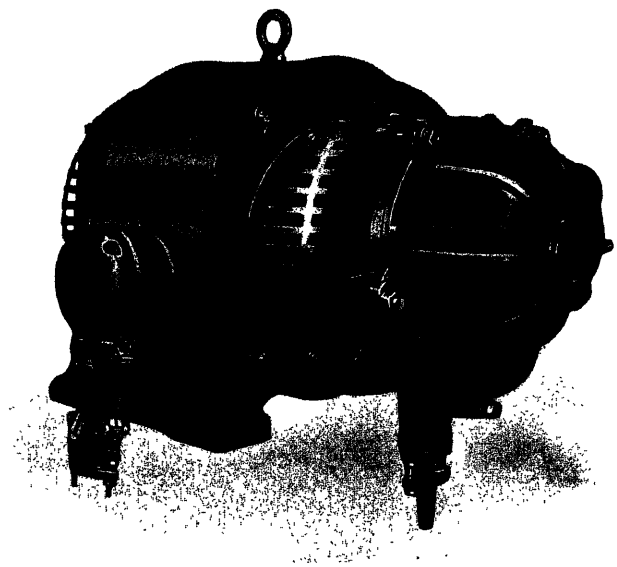


Fig. 5. Three=phase motor type MK, form B, with explosion proof enclosed sliprings.

the cause for this. The first motor had all its vents clogged up and it was almost impossible to clean it properly without injuring the winding. The second motor was also full of dirt, but it had accumulated in the lower part of the carcase and on the front end of the windings: on the core and the rear end of the windings the strong current of air does not allow the dust to accumulate.

Another advantage of the axial ventilation with a fan was also determined at this test: viz. the absence of "hot-spots" and an evenly distributed temperature throughout the motor with a fan, whereas the radially ventilated motor, even when new, shows decided "hot-spots" on the winding and the core.

The only draw-back with the axial ventilation is the necessity of having a special fan for the ventilation, as the customers only consider the fan as an emergency measure. This is only a prejudice which has its origin in the fact that unscrupulous manufacturers used to add a fan on motors with radial ventilation when the particular motor did not keep the guarantees as to temperature rise. Thus a motor with a fan has become the synonym for an illiberally dimensioned motor.

Further, these fans were designed in a hap-hazard way, almost entirely of tin-plate like Nuremberg toys, and a little rough handling of the rotor deformed or destroyed them.

In spite of this handicap, and knowing the difficulties we would have to contend with in changing the opinion about motors *specially designed* with fans, we adopted the axial method of ventilation, convinced that sooner or later the advantage of this excellent design would be acknowledged and our costomers just as satisfied with it as we were ourselves after the very extensive tests we had undertaken before definitely adopting it.

The size of the fan we adopted is not much larger than the sum of the vents in a radially ventilated machine. The efficiency is very much superior to the vents in the core. The canals in the rotor and stator are much larger and straighter

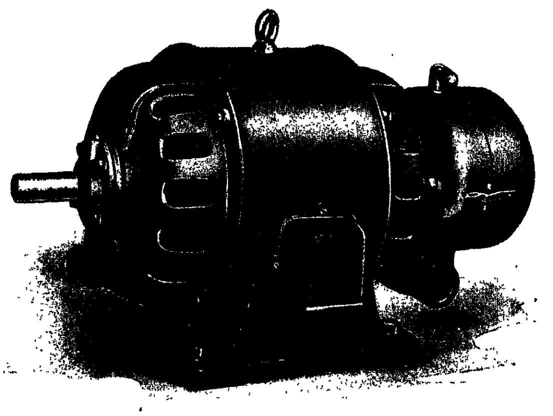


Fig. 6. Small three-phase motor type MK, form B, with slipring rotor.

and can be very easily cleaned, should the necessity arise.

Its mechanical construction is also very rigid. A fan consisting of No. 14 steel-plates is rivetted on a cast-iron hub by a large number of heavy iron rivets. Each fan is balanced and has to stand a run-away speed of 2—5 times the normal speed of the motor.

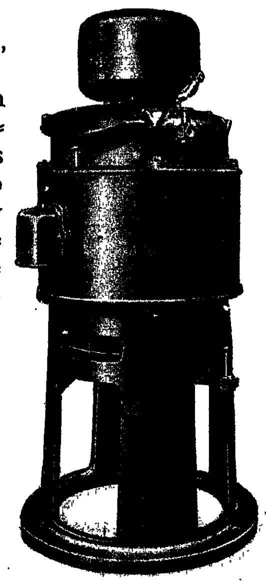


Fig. 7. Vertical three-phase motor type MK, form E, with slipring rotor.

Before this design was adopted, a fan of each type was continually reversed from 3.000 revs. in one direction to 3.000 revs. in the other. Furthermore, after more than 125.000 reversals, the fan was submitted to a run-away speed of 4.500 revs. per min., *i. e.* about 3 times the highest speed of the motor for which it was designed. The design was only definitely adopted when it was at last ascertained that the fan did not show any sign of deformation after test.

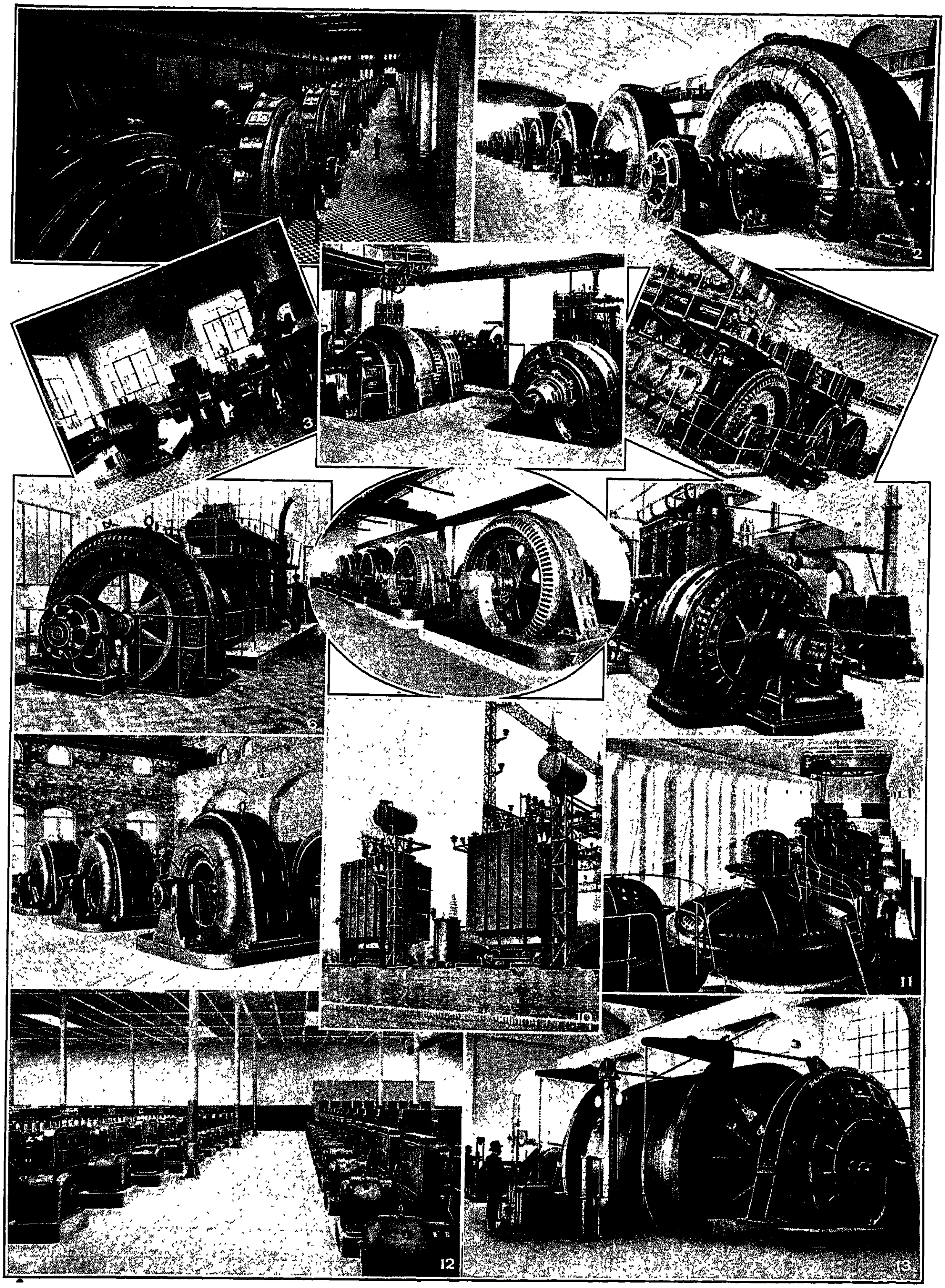
For the above reasons we consider the ball bearings and the axial ventilation of the MK motors is a real achievement in motor design — a step in the right direction to simplify and cheapen the care, and prolong the life of the motor.

A great many experiments with other details were also made before their design was definitely settled. We would only mention such a detail as the short-circuiting device. Before the new actuating mechanism of this device was accepted, a test to determine the wear, (life), of this detail was undertaken. A mechanical device reproducing the manual operation of the short-circuiting lever was installed on a motor, and the sliprings were short-circuited and the brushes lifted about 20.000 times — corresponding to about 20 years of actual service before the mechanism was inspected. No appreciable wear was observed on any parts subject to friction during this test.

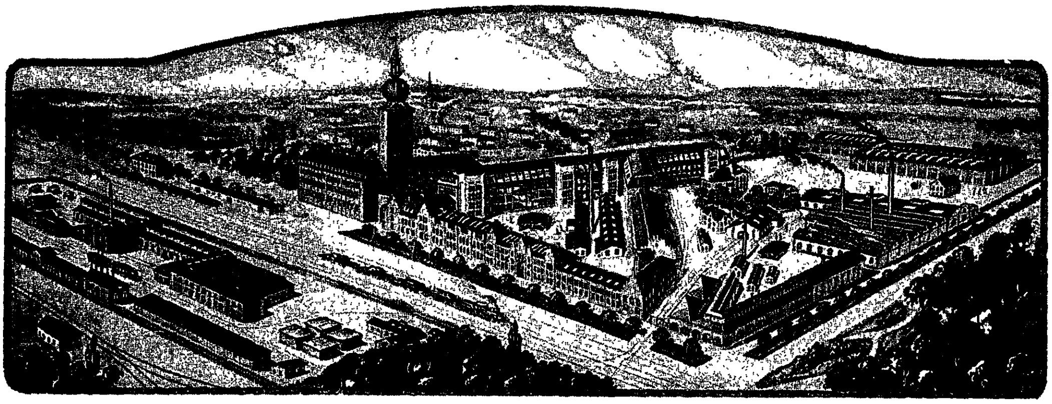
The design of the terminal arrangements of this type has been subject to special care and we can now offer our customers a complete series of different forms of terminals namely: the standard type, only protected by a drip-proof cover, an arrangement for screwed conduit, the sealing-box for wire or strip armoured rubber or paper insulated cable, allowing the customer to connect the armoured cable direct to the primary and the slipring terminals.

Further particulars regarding the sizes etc., of these motors, can be found on consulting our price list No. XVI. 1 A.

CURRENT ILLUSTRATIONS.



Some Asea-installations: 1. Sweden. 2. Norway. 3. Brazil. 4. Spain. 5. Russia. 6. France. 7. Canada. 8. Peru. 9. Japan. 10. Belgium. 11. Finland. 12. Mexico. 13. Norway.



Asea's head office and works in Vesteras, Sweden.

Vesteras 1924, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

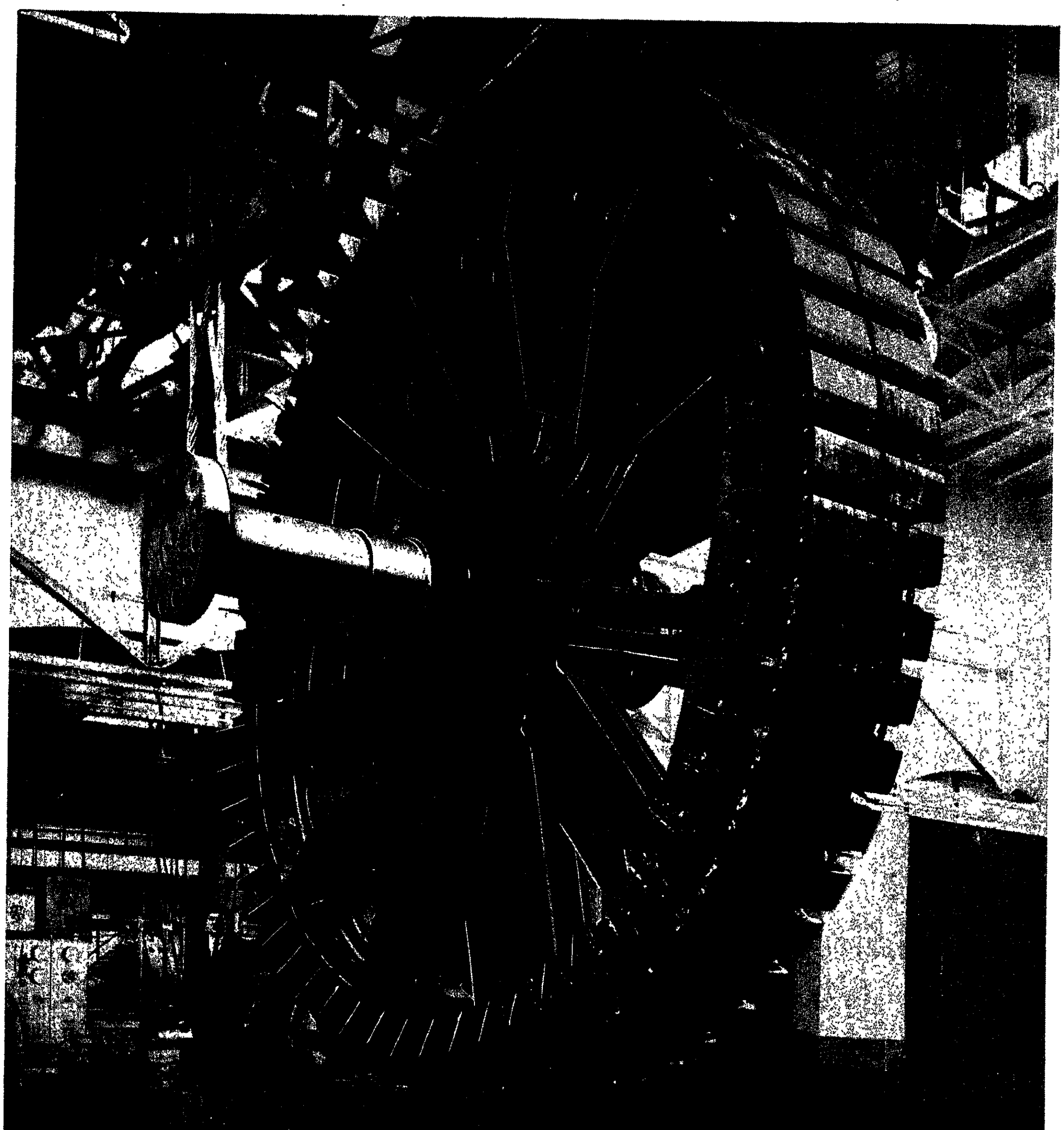
ALLMÄNNA SVENSKA ELEKTRISKA A.B.
VESTERÅS — SWEDEN

ASEA

SWEDISH GENERAL ELECTRIC LTD
5, CHANCERY LANE—LONDON

MAY 1924

All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesterås, Sweden.



The rotor of a modern, 12,000 kVA Asea-generator.

ASEA ALTERNATORS.

Asea can now look back upon more than 30 years of AC generator construction. It is one of the oldest of the large electrical firms and its wide range of manufactures is based largely on its own inventions and patents.

In 1890 Asea took up one of the inventions of its then Chief Engineer, J. Wenström, relating to the three phase system in which the AC generator — the three-phase alternator — constituted an important factor. In the same year the first three-phase generator was built under this patent, and after the invention became generally known by starting the first commercial plant in 1893, the manufacture of AC generators rapidly increased.

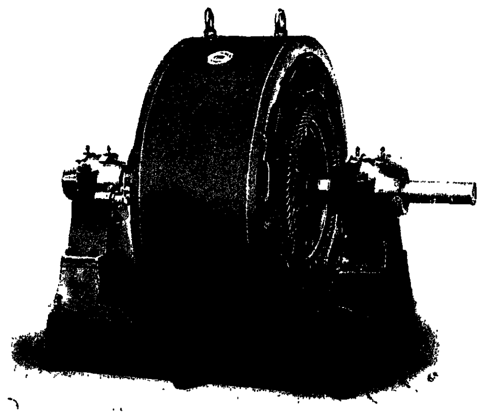


Fig. 1. The oldest three-phase generator with rotating armature.

This manufacture comprised partly standard machines occupying places in a predetermined series of generators of from 3 to 125 kVA, running at speeds in the neighbourhood of 600 r.p.m., and designed for periodicities of 60 or thereabouts, and partly special machines designed as regards size and general construction to meet the requirements of particular cases.

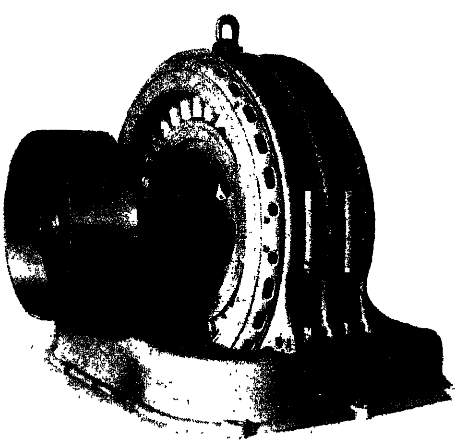


Fig. 2. Old type three-phase generator with rotating field magnets.

The standard generators were all built with stationary field magnets and rotating armatures, but the special machines, in general of large size and for slow speeds, although they were first made in the same way were soon constructed with fixed armatures and rotating field magnets, the method which is still in general use.

Asea first used this method of construction in 1896 in connection with a vertical shaft single phase generator for an output of 850 kVA. This was a very large machine at that time and was probably the biggest of its kind in the world in these earlier days.

From that time onwards all the large generators were built in a similar manner, while the original construction was retained for the small machines, covered by the standard series, until 1901. In that year however, the original series was superseded by a new one, the machines being constructed with rotating magnets and fixed armatures, like the large generators. This marked the adoption of the same system of construction for the manufacture of all general sizes of generators, and the original construction was only retained for special machines when found for any reason more suitable, and for machines of very small size.

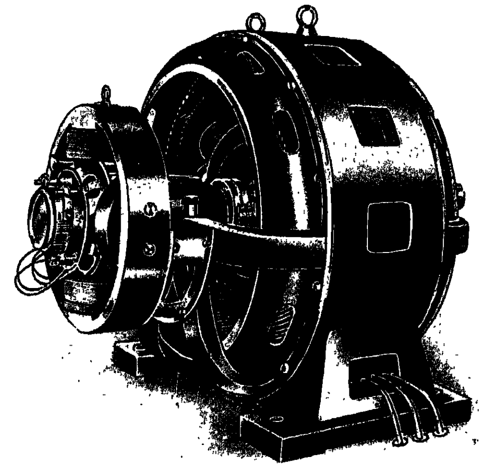


Fig. 3. Three-phase generator with rotating magnetic field and direct coupled exciter, one of the standard series of three-phase generators for the year 1904.

The rapid industrial development which took place in 1900, and in the years immediately following, was responsible for some further changes in the manufacture of AC generators,

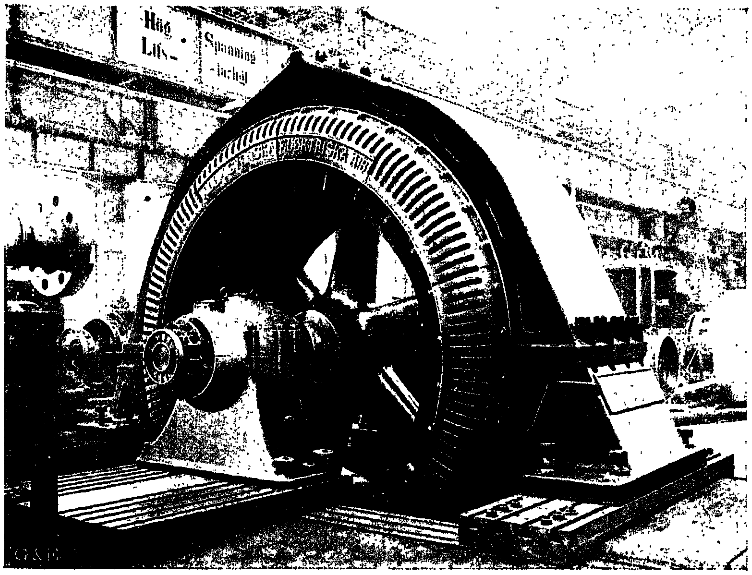


Fig. 4. One of the four world record machines for the year 1907 erected for testing.

as a commencement was made in the construction of generators whose dimensions were more or less standardised. Larger machines were brought within the standard range and other generators, which on account of their special nature required some non-standard feature, or particular method of manufacture, were still wherever possible worked into the existing series of frame sizes, the essential changes being standardised for future use as they were encountered. The first series of small generators with rotating fields soon became to some extent replaced by a more modern series embodying a larger number of sizes and having a more thorough standardisation of dimensions. At the same time Asea's output of special generators increased at an almost incredible rate during the period mentioned and culminated in the four 11,000 kVA generators which were built in 1909 for the Swedish Government. Two years earlier Asea had held the world's record for three phase generators driven by water turbines with four generators of 10,500 kVA delivered to Svaelgfos Power Station. These noteworthy achievements have been outstripped in various directions by generators built by Asea in later years, as will be gathered from what follows, but they were of quite outstanding importance at the time they were built.

In 1908 the first machines of the standard present day series of large generators were brought into the market and were followed in 1910 by the first small generators of the same type, which are covered by to-day's catalogues.

Besides the construction of alternators direct coupled to relatively slow running prime movers, or belt driven from them, Asea became at an early date interested in the construction of generators for direct coupling to steam turbines. The first of these machines, which were built in 1903, were of a construction which has now been abandoned and turbo generators with cylindrical rotors soon after became standard practice for direct coupling to steam turbines running at 3,000 r.p.m. for 50 cycles and 3,600 r.p.m., for 60 cycles. Soon after the first generator of this type was built, in 1907, a standard series of similar generators was evolved. From 1908 to 1915 machines were built in considerable numbers and several minor changes were made in the design; all the experience gained has been embodied in the present standard series, which was introduced in 1920. In 1907, 3,000 r.p.m. turbo generators of 300 kVA were built. In 1911 Asea turned out generators for the same speed but for 4,350 kVA which held a place among the largest built anywhere at that time for 3,000 r.p.m. In 1915 this size was considerably exceeded and a generator was built

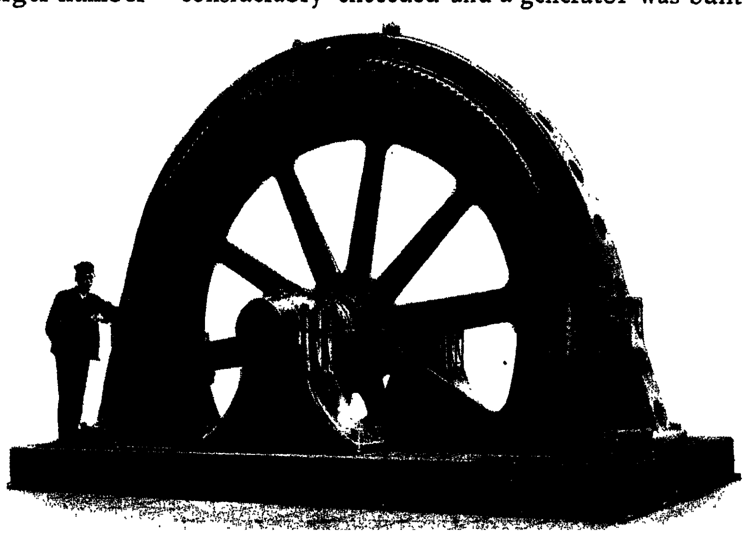


Fig. 5. The first of the 1908 year's standard series generator design, a three-phase generator 1,250 kVA, 120 r.p.m., 60 cycles, 2,400 volts for Canada.

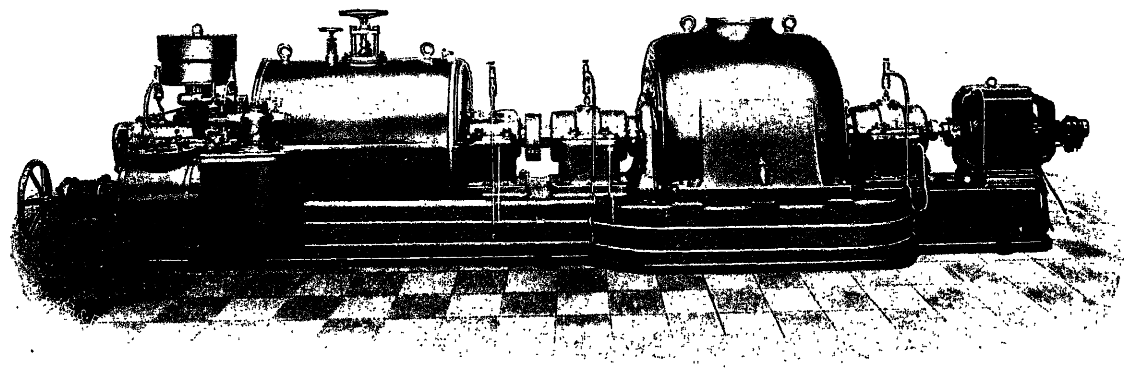


Fig. 6. Asea's first 3,000 r.p.m. three-phase turbogenerator delivered in 1907.

by Asea for 8,750 kVA, and at the same speed.

It is natural that in meeting the very varied demands arising for alternators that periodicities have been encountered outside the usual range met with in commercial undertakings, and generators with unusually high and low frequencies have been built. In these days of wireless development it is of interest to recall that Asea, as long ago as 1904, supplied a considerable number of generators for Marconi's installations.

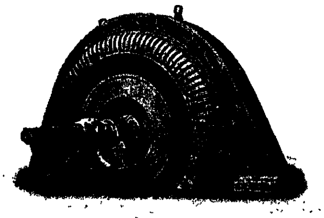


Fig. 7. 500 kVA, 375 r.p.m., 2,000 volts single-phase generator for a wireless telegraph station.

The present range of alternators manufactured by Asea includes standard generators of ordinary types with horizontal and vertical shaft for direct connecting to relatively slow running prime movers, standard turbo generators for direct coupling to steam turbines, small high speed alternators which are standardised with rotating armatures, as are also the modern radio alternators, and special machines of any required type.

The ordinary standard machines with horizontal shaft, whose construction was begun in 1908 and 1910 respectively, are still covered by two series, although various details have been altered or improved in recent years. One of these series embraces about 20 frame sizes all designed with end shield bearings and the other about 60 different frame sizes which have pedestal bearings.

The series of machines with end shield bearings can be built for speeds from 1,500 r.p.m to 250 r.p.m. with a frequency of 50 cycles and for standard outputs from 17.5 kVA at 1,500 r.p.m. to 750 kVA at 750 r.p.m. These machines are all normally of open type, but can be semi-enclosed if this is desired. They have, generally speaking, direct connected exciters, the field magnets of which are mounted on the generator end shield and the armatures carried on the generator's extended shaft end. The exciters are not provided with separate bearings of their own. These machines are designed for 50 cycles, but they can be used without any alteration in the standard dimensions for frequencies from 25 to 60 and are so designed that the larger machines can be insulated for all pressures generally in use up to 6,600 volts three phase, the windings being star connected, while the upper voltage limit for the smallest machines is 3,000 volts. As experience has shown that machines of this kind are usually only required in three different arrangements the standard product has been confined to these three arrangements only. The most common is the two bearing arrangement with free shaft end and without bedplate, which is used in most cases for direct connection or belt drive from the

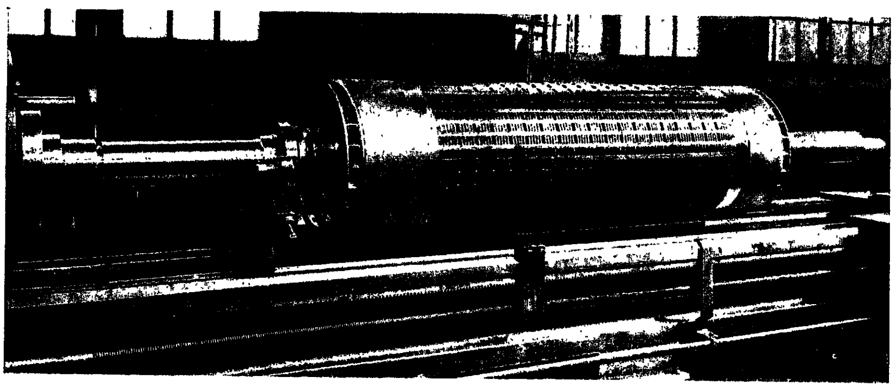


Fig. 8. Rotor for turbogenerator 8,750 kVA, 3,000 r.p.m. built in 1915.

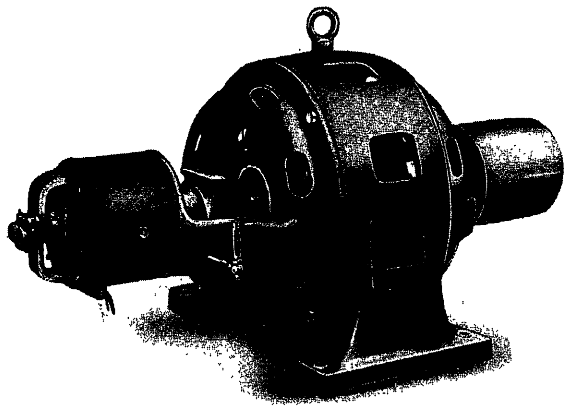


Fig. 9. Small three-phase generator of the modern end shield bearing series, with direct coupled exciter and pulley.

prime mover used. The next most in demand is the three bearing arrangement used for belt and rope drive when the pulley is of such dimensions that it cannot be carried in a satisfactory manner on the free shaft end of the first arrangement referred to. Lastly there is the arrangement with one bearing, shaft with half coupling and no bedplate, which is used when the driving motor is provided with a bedplate which is extended to carry the generator also.

On account of the extent to which standardisation of these machines has been found necessary it is not considered advisable, having regard to price and delivery time to furnish these machines with more than one definite flywheel effect, which has in any case a small value and when a larger moment of inertia is required this can be met by making use of a separate flywheel.

All machines in the series can be supplied equally well horizontal or vertical and in the latter case are provided with an upper bearing bracket which carries the combined supporting and guide bearing in addition to the exciter, and a lower bracket in which is mounted a lower guide bearing. The driving motor can be rigidly coupled to the generator shaft, the rotating weight being carried by the generator's supporting bearing, or it can be supported by its own bearing and coupled to the generator through a flexible coupling.

As any synchronous generator can also be used as a motor the generators described above are applicable when synchronous motors of similar outputs, speeds, etc. are wanted. When built as synchronous motors they can be made selfstarting without any considerable increase in price, provided they can be started light or against reduced torque. Such motors are very satisfactory for running many kinds of machinery and they are also particularly suitable for power factor correction both with and without mechanical load. The power factor problem has recently become very acute in most distribution systems and as a result Asea has delivered a considerable number of self-starting synchronous motors of this kind in the last few years.

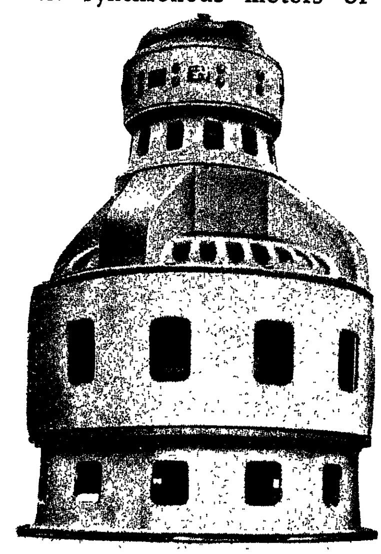


Fig. 11. Three-phase vertical generator of the modern end shield bearing series designed with thrust bearing, upper and lower guide-bearing and direct coupled exciter.

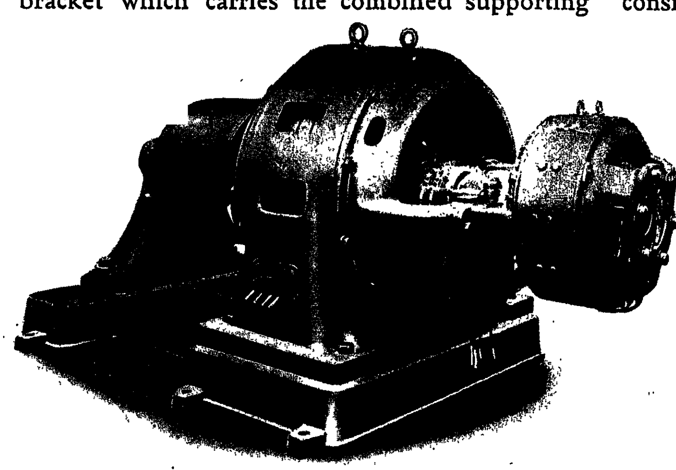


Fig. 10. Three-phase generator of the modern end shield bearing series, medium sized, with direct coupled exciter, pulley and third bearing.

The larger generators with pedestal bearings are built for outputs varying from 160 kVA at 375 r.p.m. to 7,500 kVA at 150 r.p.m., the highest standard speed being 750 r.p.m. at 50 cycles, and the lowest 94 r.p.m.. The series can be used without alteration for frequencies varying from 40 to 60 at corresponding speeds. They are so designed that the larger sizes can be wound for voltages up to 11,000 and the smaller sizes up to 6,600, three phase star connected.

As these machines have to meet conditions of widely varying character they are designed so that they can be easily constructed in many different forms. They are normally of open type, but can all

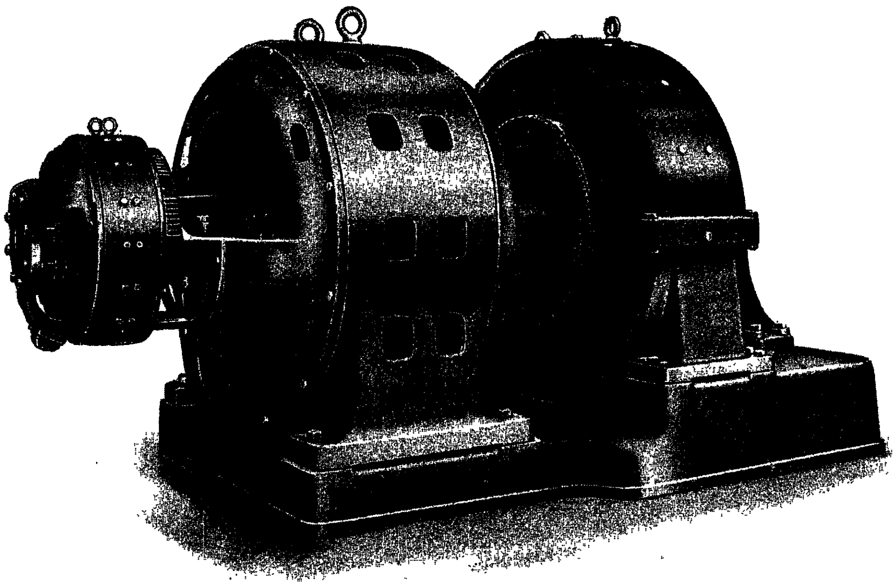


Fig. 12. 500 kVA motor generator set 500 r.p.m., 50 cycles consisting of selfstarting synchronous motor with exciter and direct current generator.

be supplied semi-enclosed or totally enclosed. In the former case they are provided with covers which only hinders the ventilation to a very small extent and allows circulation of air between the machine and the machine room. In the latter case the covers and stator frame are so constructed that the air inside the machine and in the machine room do not, in general, come into contact. Cooling air must accordingly be brought to the machine through special air ducts constructed in the building and the heated air let out in a similar manner. These machines have as a rule two bearings, shaft with free end or forged flange, and bedplate. The exciters are overhung as in the end shield bearing generators, but the magnet frames are in most cases carried upon an extension of the bedplate beyond the outer bearing. Besides the usual standard arrangement a large number of other arrangements are in use, for example, machines without one or both of the bearings, without bedplate, and even without shaft, in which case these parts are supplied by the makers of the prime mover.

It is not only possible to vary the form and arrangement of these machines, but also the flywheel effect embodied in the rotors, which can be altered within wide limits. Only in the case of the smallest types when designed for the higher speeds is it possible to supply only one flywheel effect. At other speeds even for these types considerable variations are possible. This is brought about partly by suitably changing the dimensions of the rim of the field magnet wheel, and when the required momentum can no longer be embodied in this, by adding one or two side rings, which are carried by the magnet wheel and do not require separate bosses. Other methods of construction can also be used when extra large flywheel effects are required without making it necessary to depart from the standard dimensions.

Most of the machines belonging to this series are arranged for direct coupling to various driving motors. To suit the inherent characteristics of the driving motor there are several standard

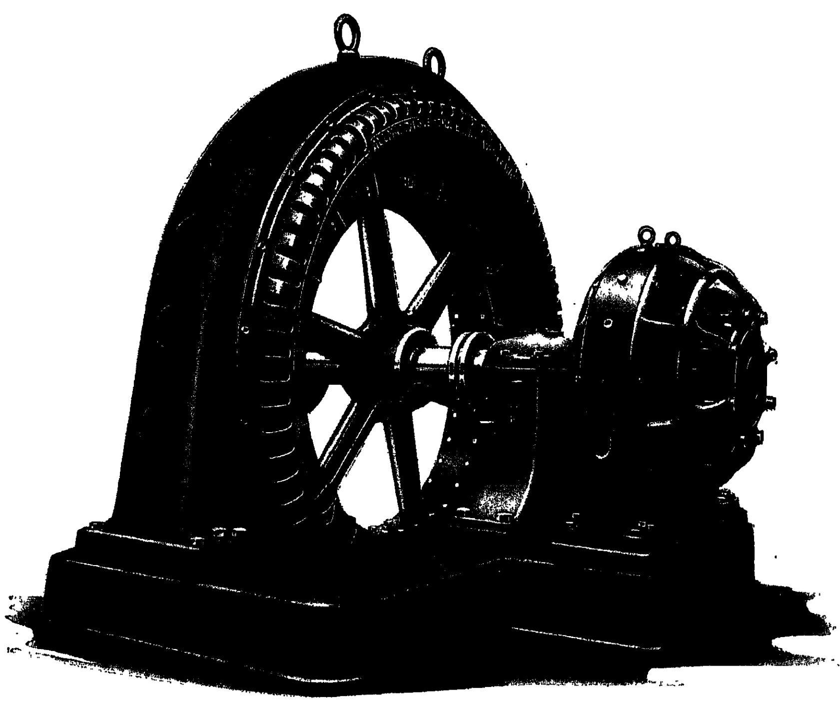


Fig. 13. Standard open type generator with pedestal bearings.

constructions for generators, for example if they are required for direct coupling to gas engines which have low run away speeds, or to modern water turbines which have high run away speeds. Again with the large generators now required it is not possible, except in the case of some end shield bearing machines, to count on being able to transport them completely erected from factory to power station. They are accordingly made in such a manner that they can be dismantled for transport and also taken apart for inspection and necessary repairs with a minimum of trouble, all parts being carefully made to gauge and template. As in the case of

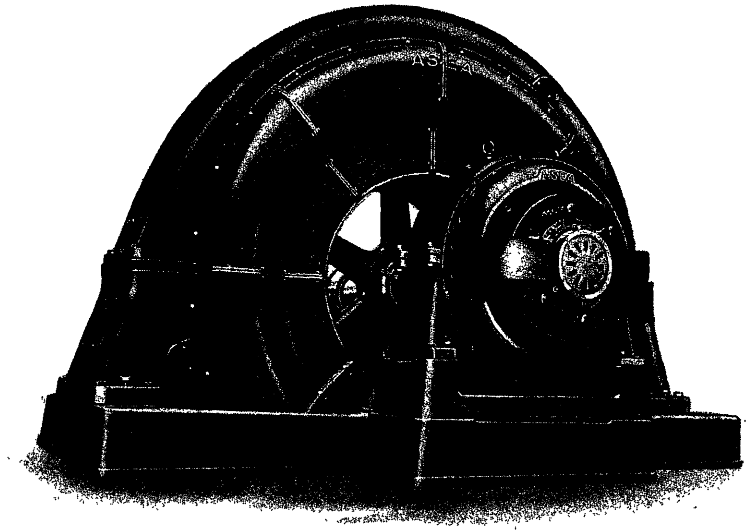


Fig. 14. Modern semi-enclosed generator with pedestal bearings.

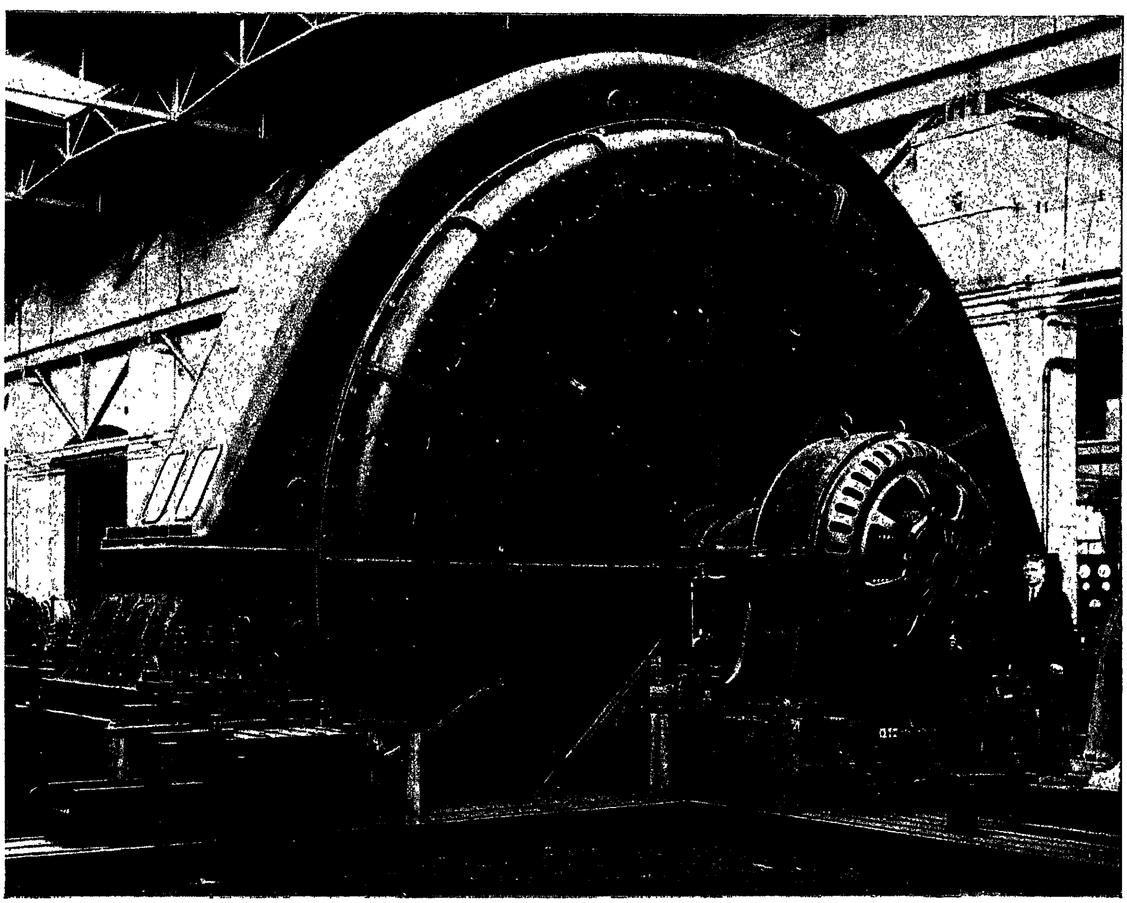
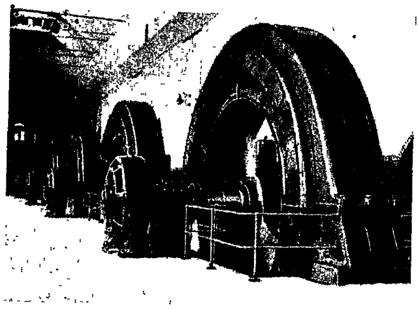
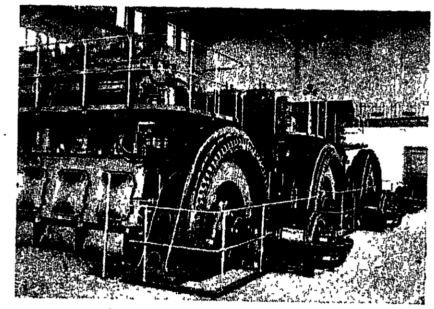


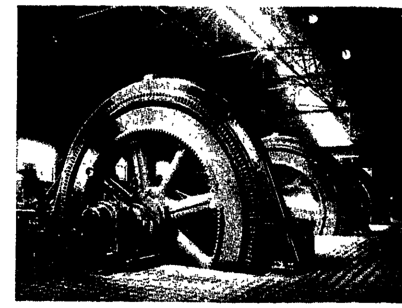
Fig. 15. Modern totally enclosed generator designed for 12,000 kVA, 107 r.p.m., 50 cycles, 12,000 volts.



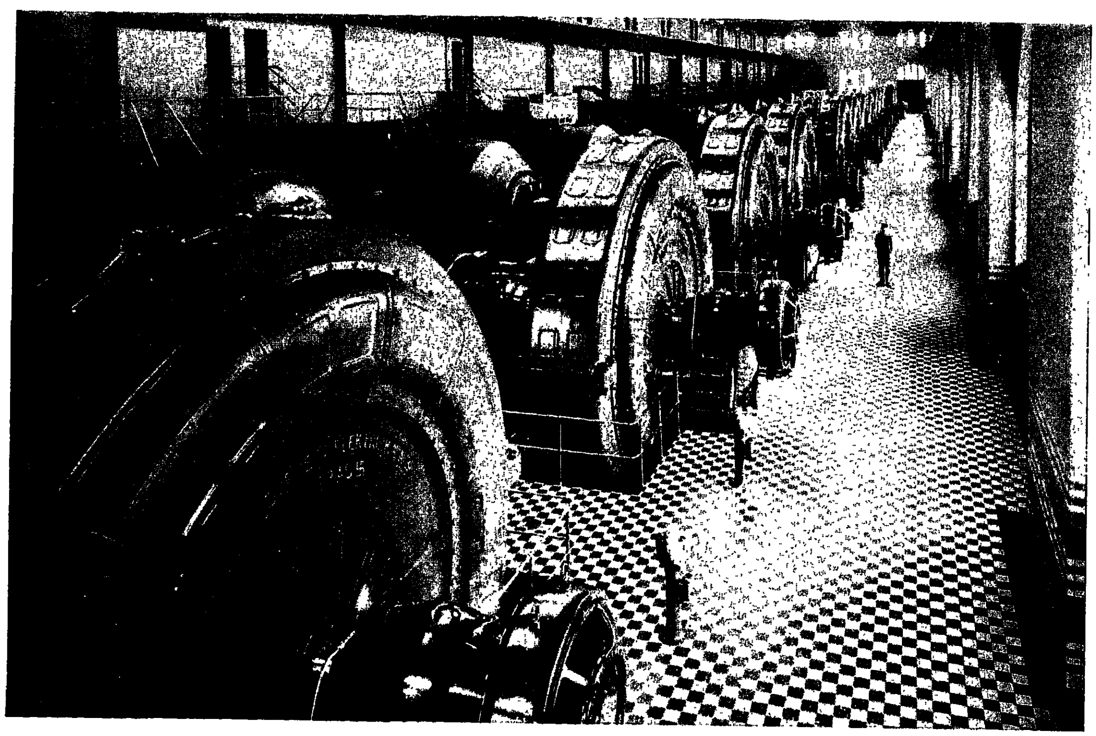
The City of Stockholm power station, Sweden.



Moscauer A. G. Cement Factory power station, Podolsk, Russia.



Oxelosund's Iron Work power station, Sweden.



The Swedish Government power station Trollhattan, Sweden, 165,000 kVA in Asea generators.

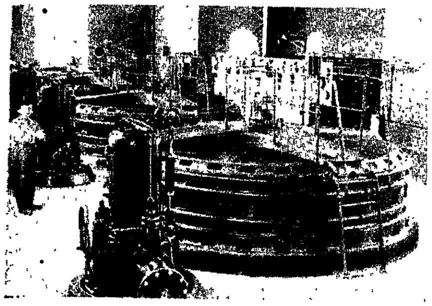
The Swedish Gov
Alvka

The Swedish Gove

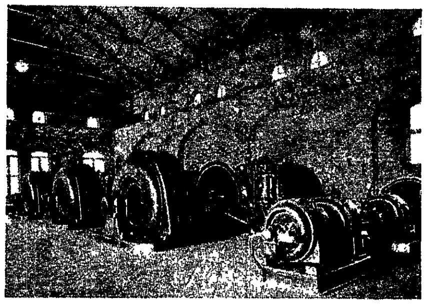
Raanaasfos Power Station, Norway.

The City of Bjorneborg power station Aetsa, Finland.

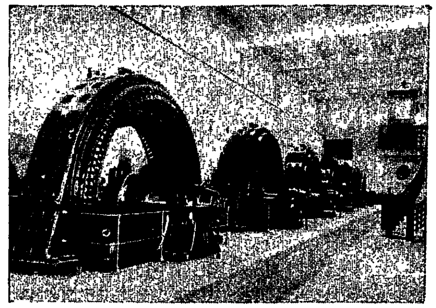
Sté d'Electricité du Littoral Normand, France.



Sidney Electric Power Co. Dam 2, Canada.



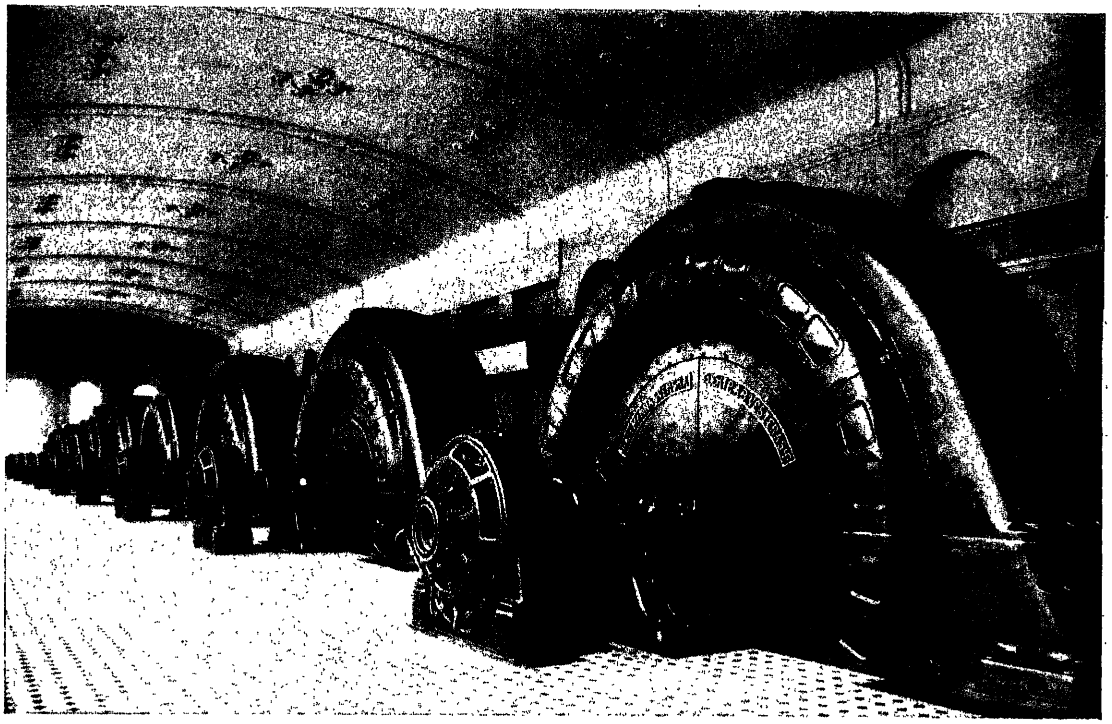
The Power Station Sagami I, Japan.



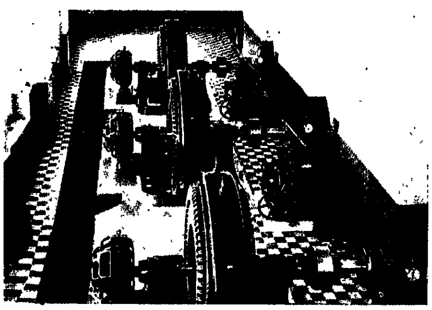
Bullerforsen's Power Station, Sweden.

at power station
weden.

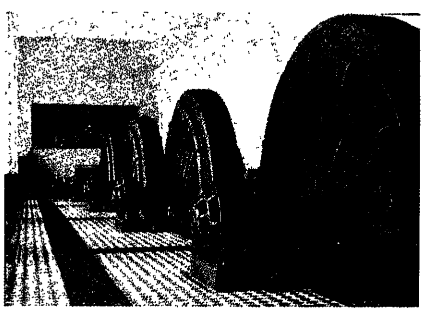
ower station Porius.



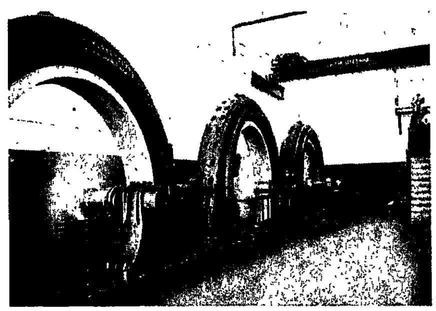
Saaheim Power Station, Norway, 113,400 kVA in Asea generators.



The Power Station Cabriana, Spain.



Anjalakoski Power Station, Finland.



E. B. Eddy Co. Power Station, Canada.

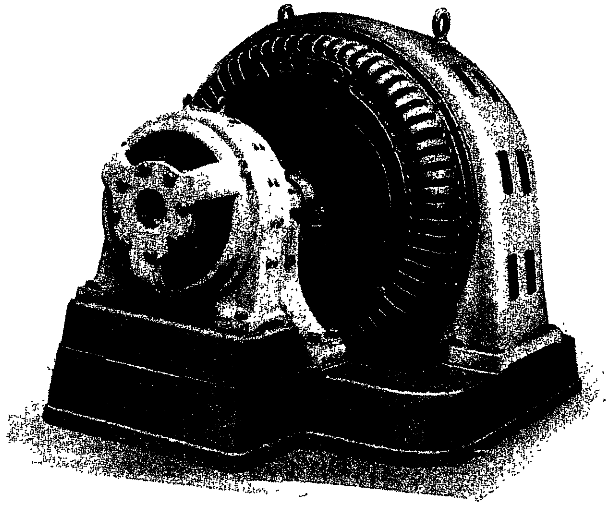


Fig. 16. 1,100 kVA three-phase generator 750 r.p.m., 50 cycles, 3,000 volts, for Belgian Congo.

the smaller series referred to above all generators belonging to the larger series can be provided with vertical shaft. They are normally provided in this case with combined supporting and guide bearing and upper bracket which also carries the direct coupled exciter, if one is used. The upper bracket and supporting bearing can also be made sufficiently strong to support the rotating parts of a water turbine and also any unbalanced water pressure. The turbine is then rigidly coupled to the generator shaft and requires only a suitable number of guide bearings.

The machines belonging to the larger series can also be used as synchronous motors, the smaller sizes being started as previously described. The larger types usually run up to speed with a starting motor or auto-transformer starter so as to avoid heavy disturbance on the power net work.

The turbo generators which Asea now builds

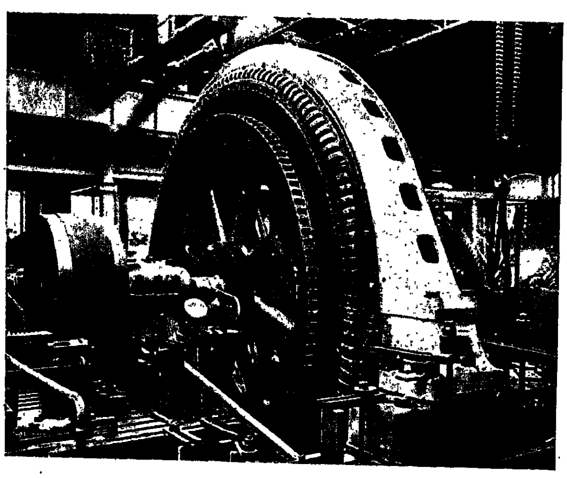


Fig. 17. Modern open type three-phase generator with large flywheel-effect in the rotor, delivered to a cotton-spinning mill in India.

belong to a series covering 20 sizes and are designed with outputs from 160 to 12,500 kVA at 50 cycles and 3,000 r.p.m. They can at the same time be used for frequencies as low as 40 and, with the exception of the largest sizes, also up to 60 with corresponding speeds. The largest size can be supplied for any voltage up to 11,000 three phase star connected and for the smallest the upper limit has been placed at 3,300 volts. All turbo generators are made totally enclosed, the ventilating openings having flanges for connection to the power station cooling air ducts. As regards arrangement they have been standardised with two bearings and without bedplate. The bearings' housings are cast in one piece with the end covers which protect the windings and in this way the bearings are set very close together, which is a marked advantage both in respect of space requirements, and of the critical speed of the rotor. Ventilation which is an important problem in these machines is arranged on the axial system, which

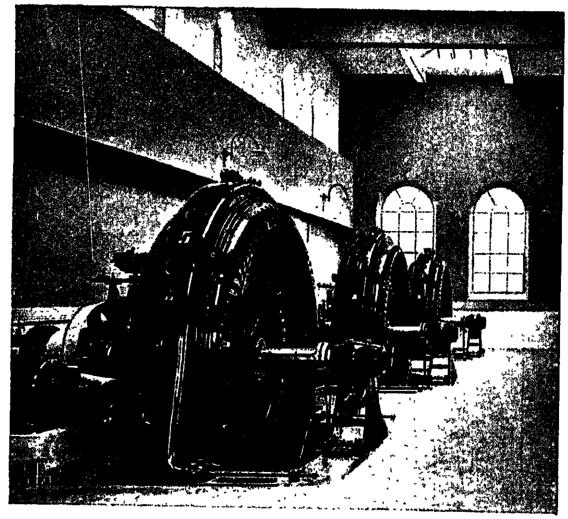


Fig. 18. Modern open type three-phase generators with pedestal bearings, bedplates and sliding stators.

offers the most satisfactory result in the circulation of the cooling air through the machine. This is done by a fan mounted upon the shaft and so proportioned as to be capable of disposing the cooling air through the different parts of the machine where it absorbs the generated heat.

The two pole rotor is of the "parallel slot" type which allows a simple and at the same time particularly practical accomodation of the field winding, which can be permanently embedded during manufacture in such a manner as to prevent any displacement during subsequent running. The insulation of the rotor winding consists of absolutely fire proof material. The

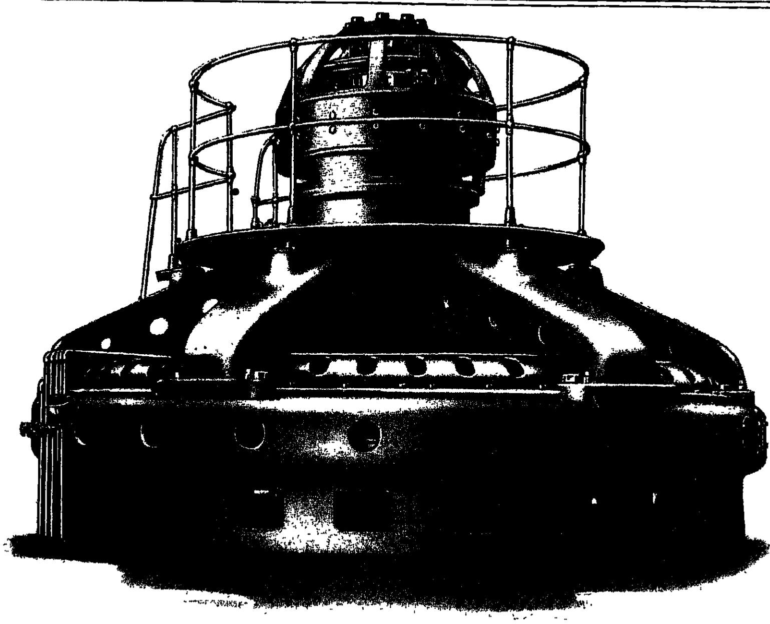


Fig. 19. Modern vertical three-phase generator with direct coupled exciter, 1,000 kVA, 150 r.p.m., 50 cycles, 420 volts delivered to New Zealand.

machines can be supplied for separate excitation but as a rule are provided with a direct connected exciter. The exciter voltage has been standardised at 65 volts for the smaller machines and at 110 volts for the larger, but if there should be any particular reason justifying a change the largest machines can be designed for excitation at 220 volts.

During the last few years in which machines of Asea's new turbo series have been running abundant evidence has been forthcoming that all demands have been fulfilled, while on test their efficiencies have proved to be remarkably high.

Of the standard generators manufactured by Asea it now only remains to mention the high speed generators with rotating armatures and fixed fields, and the generators for wireless telegraphy. The first are to all intents and purposes DC machines, which are provided with sliprings so that they can be used as AC generators, but have commutators in addition and are self-exciting. They are supplied however without commutators when the exciting current can be supplied from an external source, or from a direct connected exciter. The standard outputs vary from 3.5 to 9.5 kVA at 1,500 r.p.m. and 50 cycles and 400 volts as a maximum. The arrangement is only with two bearings, free shaft end and no bedplate and of standard open type. The last — the generators for wireless telegraphy — also have rotating armatures and fixed fields and are covered by a series of 20 sizes, for 2 frequencies namely 500 and 1,000 cycles at either 1,500 or 3,000 r.p.m. The greatest output is at present 23 kVA at 1,500 r.p.m. or 3,000 r.p.m. and the smallest 0.04 kVA at 3,000 r.p.m. and a frequency of 500. They are naturally single-phase and are designed for any required voltage up to 220. The magnetising current is supplied from a separate source and is usually at 110 volts, though higher or lower voltages can be used. These generators are also supplied in the normal open construction having ball bearings, shaft with free end, and without bedplate.

Owing to the rapid industrial development which still continues it is natural that in time a standard series, originally perfectly satisfactory, becomes gradually unsuitable to meet changing requirements. Other reasons also make it necessary to depart from or to alter standards at times. As mentioned before, Asea's present types have several times in recent years been revised and extended to meet advancing demands for a product up-to-date in all respects. They also continually undergo improvement, such as by the adoption of newer methods of design and

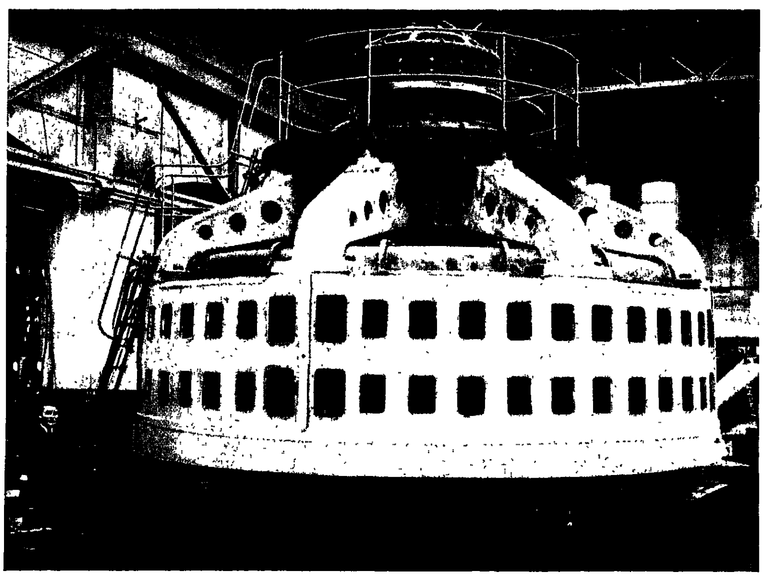


Fig. 20. Modern vertical three-phase generator 10,000 kVA, 187 r.p.m., 25 cycles, 11,000 volts with direct coupled exciter for a Canadian power plant.

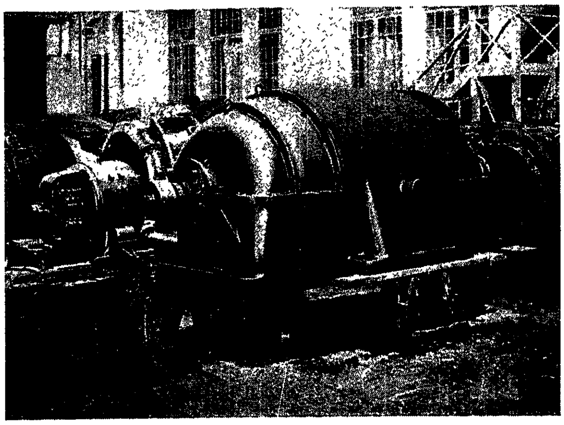


Fig. 21. Modern turbogenerator 3,000 r.p.m., 50 cycles with end shield bearings and direct coupled exciter.

calculation, improved materials of construction, and methods of machining etc., and these combine to ensure that the manufacture of generators is continually on the up grade.

At the same time there is a definite limit beyond which standardisation is inadvisable and it is accordingly not always possible to select a suitable machine from the standard types to fulfil some special purpose.

As in the early times which has been reviewed above, and before the modern standard series came into use, Asea built several special machines departing from the earlier standard types and now continues to build a large number of machines which in some way or another vary from the modern standards.

It is most usually the size of the machine which makes this departure advisable, but the reason may be the requirement of some special speed or frequency, voltage etc. for which the standard machines are not designed.

It has been stated above that Asea held the world's record in 1907 for large generators driven by water turbines, by the manufacture of generators for Svaelgfos Power Station. This achievement was later repeated in 1915 by the delivery of the 18,900 kVA generators to the Norwegian installation Rjukan II. More lately Asea has built still larger machines of the same kind and in 1918 delivered two generators of 22,000 kVA and in 1920 one of 24,000 kVA. These machines are not now the largest generators in the world built for hydro-electric developments, but are certainly the largest which have been constructed in Europe.

Fig. 23. Modern type high speed generator with rotating armature and fixed field.

The extension of the limits of speed between which prime movers can be constructed has naturally involved the building of suitable generators. On the upper limit are steam turbines and on the lower large gas engines and water turbines. For direct coupling to the last type of machines Asea is building at present some generators for an output of 10,000 kVA at 62.5 r.p.m. and also has in hand a number of generators for 8,750 kVA at 75 r.p.m. All these are to be manufactured in the vertical arrangement.

In other directions also various noteworthy machines have been supplied by Asea. In 1915 three single phase generators were supplied, each for a maximum output of 10,000 kVA at 225 r.p.m., 15 cycles, 4,000 volts. These were for the Power Station which supplies the electrified railway connecting the Swedish iron ore

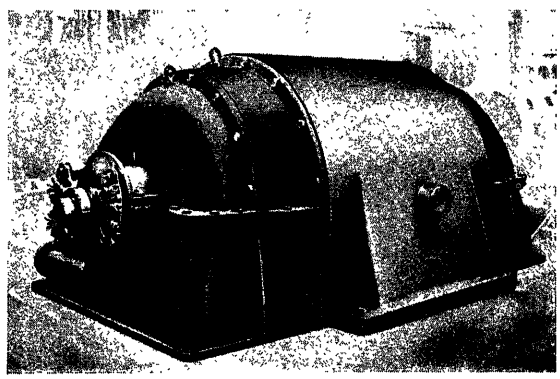


Fig. 22. Modern turbogenerator 2,000 kVA, 3,600 r.p.m., 60 cycles, 2,300 volts, delivered to China.

workings (at Gellivare and Kiruna) with the Atlantic ports, the most northerly electrified line in the world lying almost entirely above the Arctic Circle. These generators were for a long time the largest of their kind in the world.

In 1903 a three phase generator was built by Asea for an output of 1,830 kVA and wound for 20,000 volts, and this machine, together with a duplicate which was delivered the year afterwards, is still in service after more than 20 years.

Practice in recent years however, has been in the direction of winding generators for lower

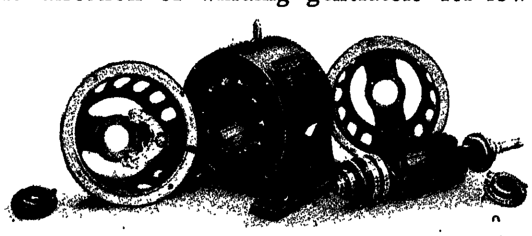


Fig. 24. Modern Asea generator for wireless telegraphy.

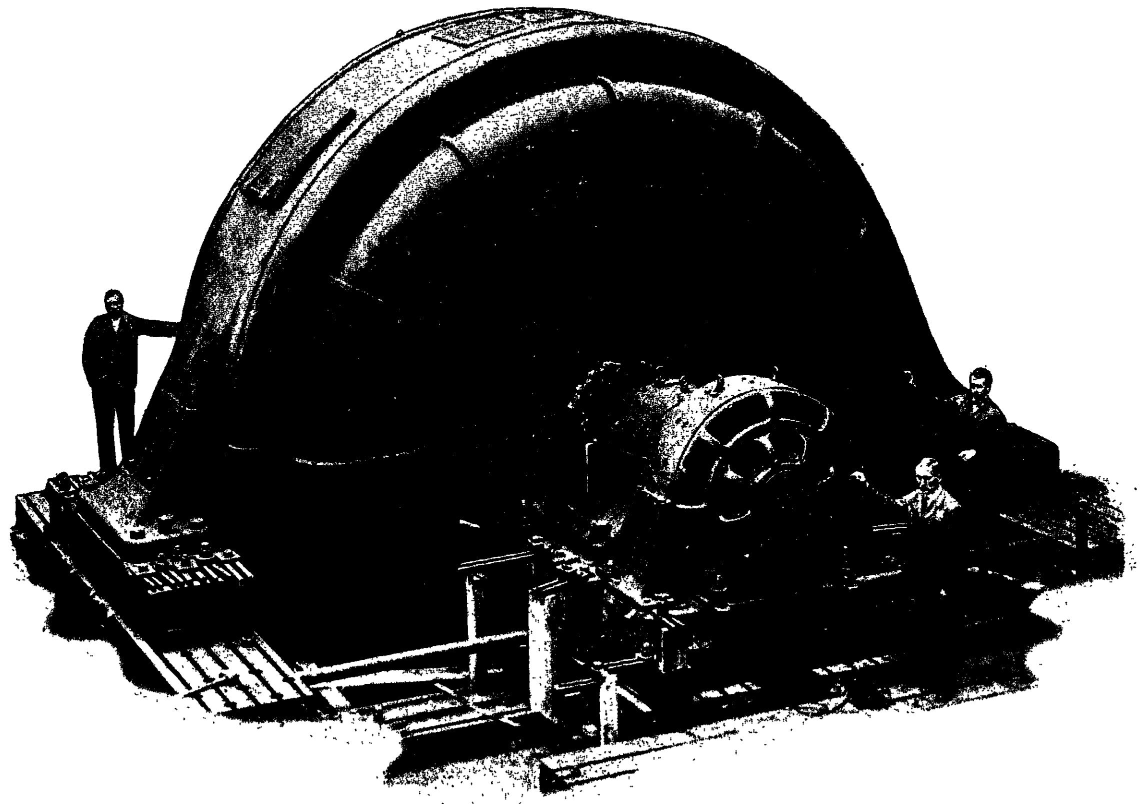


Fig. 25. 24,000 kVA three-phase generator 300 r.p.m., 25 cycles, 15,000 volts for the Norwegian Government Power Station at Glomfjord.

voltages, as this has been found most satisfactory. The pressure can afterwards be stepped up in transformers to the voltages used in the present day overhead power lines. It has accordingly not been necessary to carry out any special researches in the direction of insulating generators for exceedingly high voltages and for most of the big generators built by Asea a pressure of 11,000 volts has not been exceeded. An exception was made in the case of the 22,000 and 24,000 kVA generators, which have been referred to, these being wound for 15,000 volts.

Another special requirement which should be noticed is that of large flywheel capacity. In the case of internal combustion engines particularly large flywheel capacity is necessary to obtain satisfactory working. Among the many

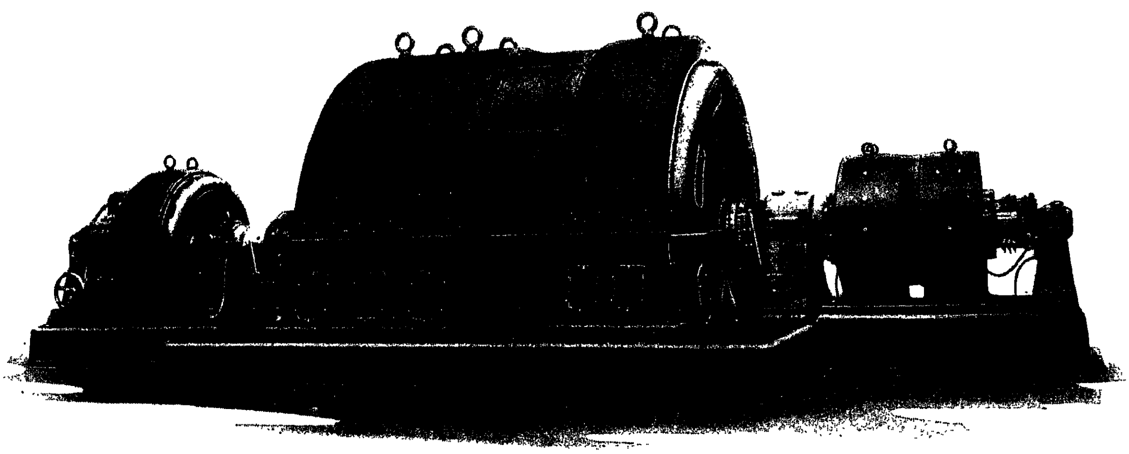


Fig. 26. 3,400 kVA single-phase three-phase motor generator set, 300 r.p.m., 15/50 cycles, and 3,000/5,500 volts.

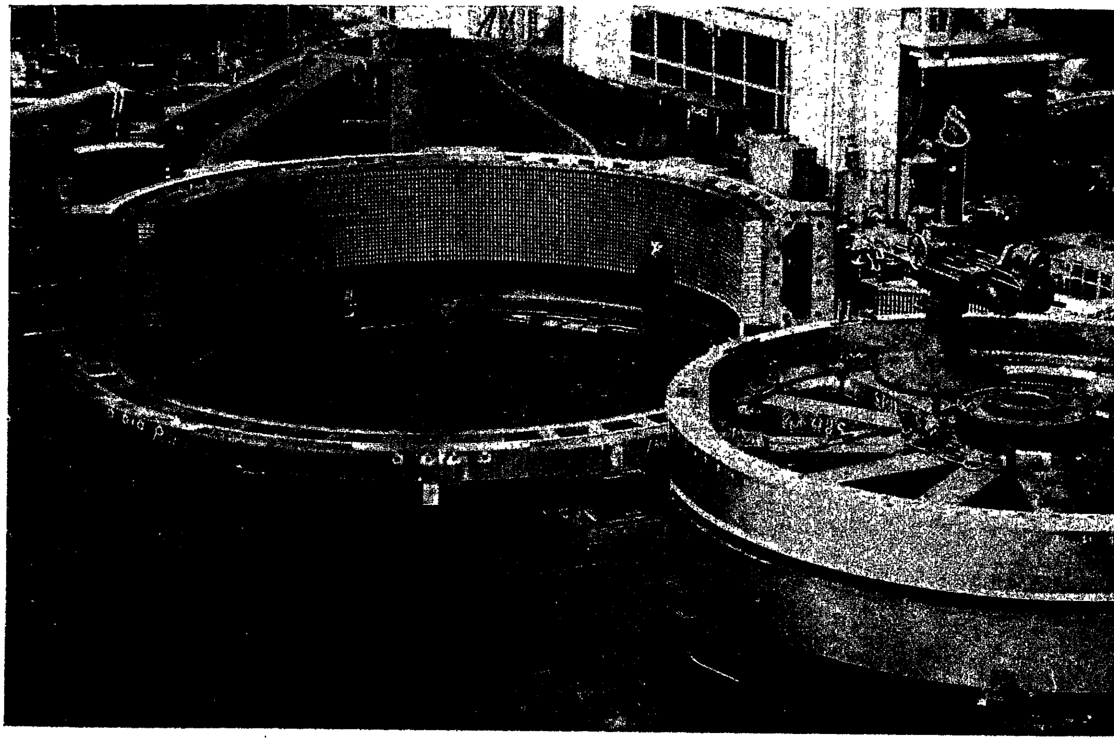


Fig. 27. Bearing bracket, stator and rotor in preparation for one of the three vertical three-phase generators each for 10,000 kVA, 62.5 r.p.m., 25 cycles, 10,000—11,000 volts, for the Swedish Government Power Station at Lilla Edet.

generators built for such service the most worthy of note are three of 1,300 kVA at 94 r.p.m. and 50 cycles which are designed with a flywheel capacity of 1,600,000 kgm^2 contained in their rotating magnetic field.

In an abbreviated review such as has been given above it has not been possible to do great justice to all the different kinds of alternators which Asea is able to manufacture. It will, however, have been made sufficient clear that with its present standard range of generators, based in all respects upon the best modern practice, and its equally noteworthy special generators, Asea is in a position to furnish the most suitable alternators for any installation that may be in question.

Asea's world wide experience from more than thirty years of supplying generators is without doubt its best guarantee of first class design and construction.

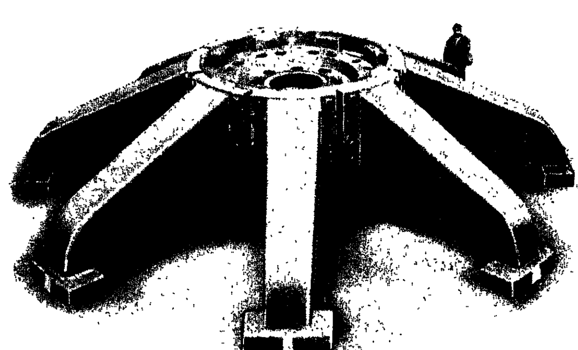


Fig. 28. Top bearing and supporting arms for 10,000 kVA vertical three-phase generator.

CURRENT ILLUSTRATIONS.

Transport of an Asea machine in Belgian Congo.

Amongst Asea's deliveries for foreign countries, a couple of equipments for rather exotic territories are the most interesting ones at present.

They are situated in places so far separated from each other as Katanga in Belgian Congo and Bombay in India, the former comprising equipment for a large, new Cement Factory, the latter the electrification of not less than eight spinning mills.

The African plant, the erection of which is now almost finished, comprises 2 three-phase generators, each 1,100 kVA, 750 r.p.m., 50 cycles, 3,000 volts, with re-inforced insulation for tropical climate, 3 oil cooled three-phase transformers, each 550 kVA, 3,000/15,000 volts, 3 ditto, each 550 kVA, 15,000/550 volts, together with high and low tension switchgear.

The Indian delivery consists of 314 three-phase motors with a total output of 17,592 h.p. in sizes varying from 3 to 250 h.p. per machine. The motors are executed partly semi-enclosed, partly for pipe ventilation, and a small number totally enclosed. The delivery also includes, complete switchgear for the high tension side, 22,000 volts, as well as for the low tension side, 450 volts, for all the eight spinning mills. The large quantity of switchgear supplied included no less than 89 oil circuit breakers, type HL, and 98 oil circuit breakers, type HO, for voltages from 11 to 20 kV and currents from 350 or 500 amps.; further, 287 current transformers, 408 disconnecting links for currents up to 1,500 amps., and 1,870 supporting insulators from 3,3 to 6,6 and 22 kV etc.

Asea's erecting Engineer and assistants in Bombay, India.

Already during 1916—17 Asea delivered to the same firm two three-phase generators, 700 and 1,250 kVA resp., at 167 and 150 r.p.m. resp., 50 cycles, 460 volts, with built in flywheels.

One of the illustrations shows the transport of a machine piece for the Katanga plant, and the other Asea's Erecting Engineer with assistants in one of the Indian power stations.

Vesteras 1924, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

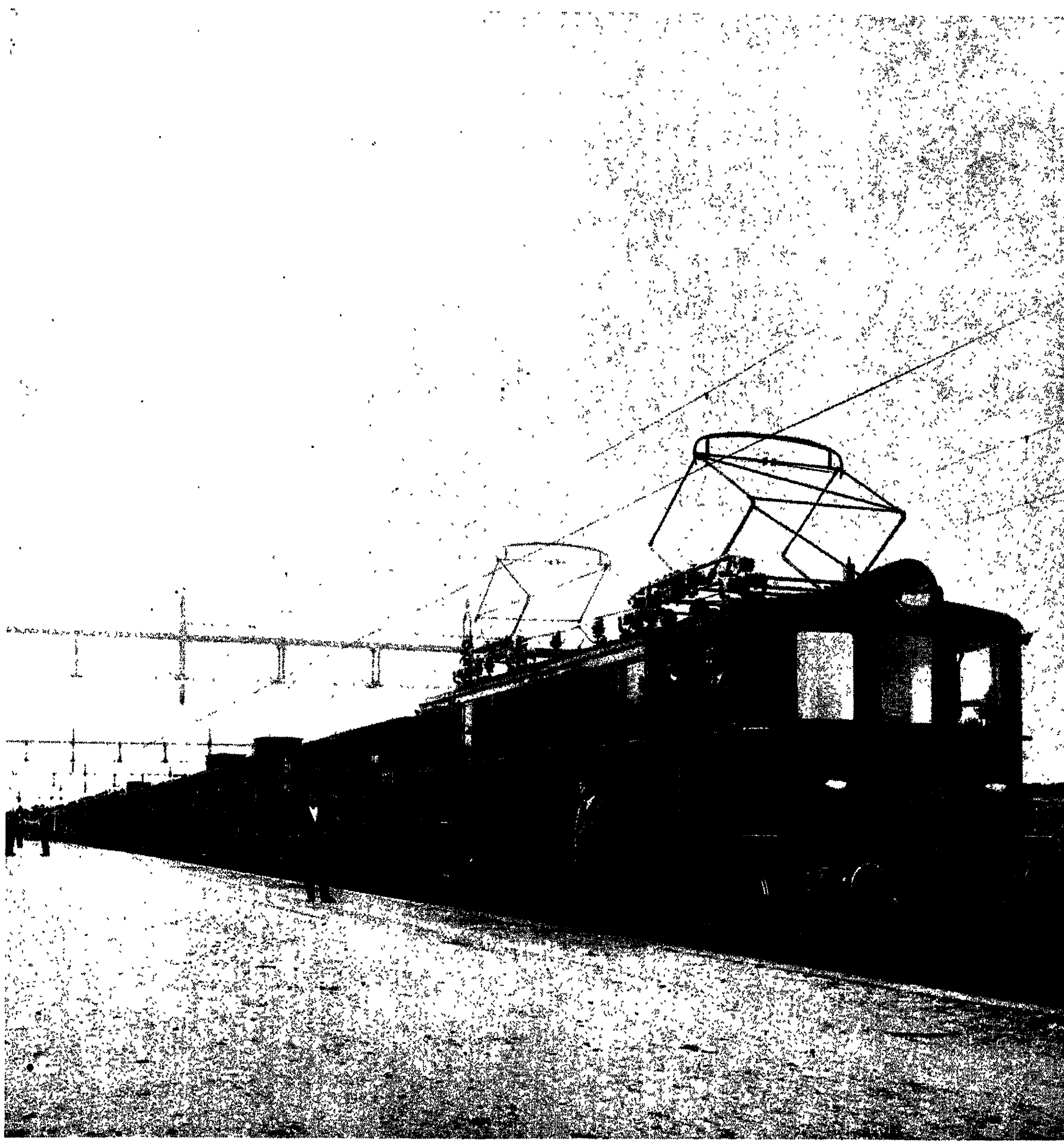
ALLMANNA SVENSKA
ELEKTRISKA A.B.
VESTERAS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5. CHANCERY LANE—LONDON

JUNE

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesteras, Sweden.
Permission is given to reprint articles or extracts from this journal,
on condition that the name — Asea-Journal — is clearly stated.

1924



Train on the Riksgrans Railway, Sweden.

ELECTRIFICATION OF THE IRON ORE RAILWAYS IN LAPLAND.

If one excepts the small railway from Borensberg to Klockrike, the first line electrified in Sweden on the single phase system is the so called Riksgrans (Border) Railway or the 120 kilometer length of line between Lulea and Riksgransen, the route of which is shown on the map below.

The necessary powers for this were granted by the Swedish Riksdag in 1910 and in the same year the order was placed with Asea and S.S.W. these two firms not only making themselves responsible for the supply of all equipment, but also giving a guarantee as to the running costs over a number of years.

The power station at Porjus was begun in 1910 and was completed by the end of 1914. The transformer sub stations, four in number, were commenced in 1912 and were finished at the beginning of 1914. The overhead lines which included 240 kilometers of 80,000 volts transmission line and 150 kilometers of trolley line wire were commenced after a good deal of preparatory work in 1912, and were completed by the autumn of 1913. The electric locomotives, which comprised 14 1,800 h.p. goods engines of type 2—6+6—2 and 2 1,000 h.p. passenger engines of type 4—4+4—4 were delivered in 1914 and 1915.

Trial runs commenced in June 1914 the power being supplied by the Kiirunavaara A.B. As soon as the Porjus power station was completed the first ore trains were electrically driven and by July 1915 all trains on the Riksgrans Railway were running electrically.

The installation worked so well from the outset and the running costs were so decidedly lower than had been guaranteed, that the two firms were soon released from their undertaking in this respect and the Swedish State Railway Board took over the line complete.

By 1916 the State Railway Board had already submitted a further proposal to continue the electrification from Kiruna to Lulea and further powers were granted by the Riksdag in 1917 enabling the Kiruna—Gellivare—Nattavara section to be electrified.

Asea obtained the order for the supply of equipment and the four additional static substations required. For this section a further four 1,800 h.p. 2—6+6—2 locomotives were necessary and the order for the electrical equipment of these was placed with Asea.

The Kiruna—Gellivare section was taken into use at the beginning of 1920 and the Gellivare—Nattavara section during 1921. For running these two additional lengths of line it was not found necessary to undertake any extension of the Porjus power station.

Later, in 1920, the Riksdag granted powers for continuing the electrification over the section Nattavara—Boden—Lulea—Svarton (see map) using five static sub-

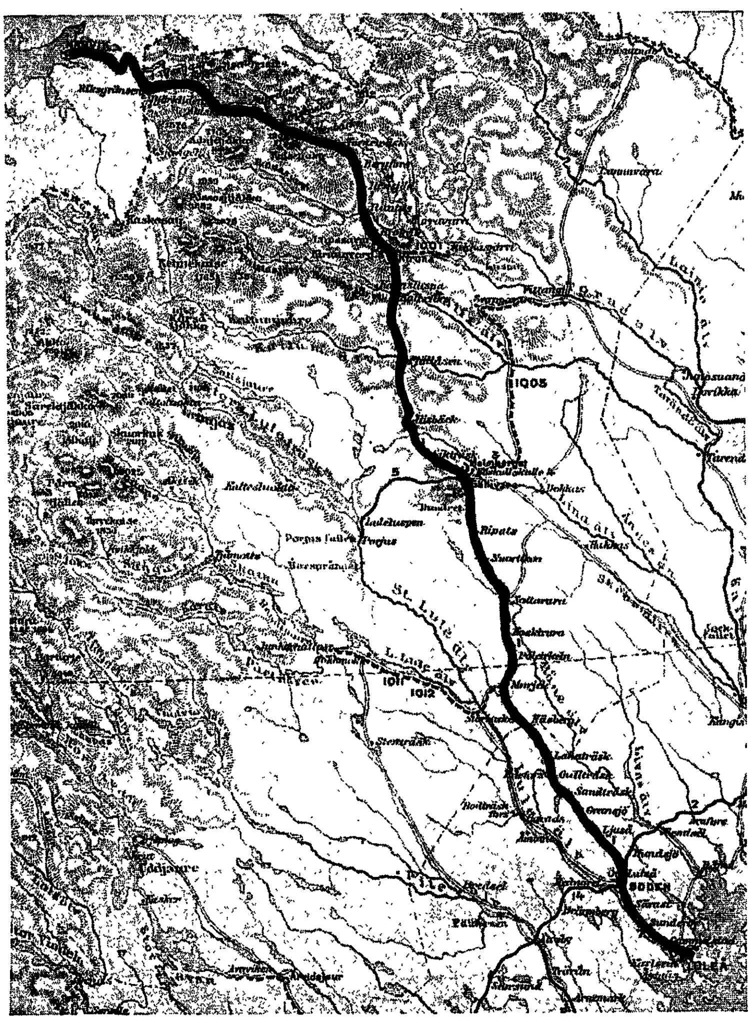


Fig. 1. Map showing the Riksgrans Railway, Sweden.

Fig. 2. A 2,100 tons ore train with two locomotives on the Riksgrans Railway.

stations for which Asea received an order for equipment and switchgear as before and also for a further single phase generator with switchgear for extending the power station at Porjus.

In addition an order was placed with Asea for 12 electric locomotives including 10 1,200 h.p. goods engines type 0—8—0 and 2 2,400 h.p. passenger engines of type 4—4+4—4. As the overhead equipment was completed and the locomotives delivered electric working was extended, — to Boden in March, and to Lulea and Svarton in August 1922.

This completed the electrification of the Lapland iron ore lines which have a total length of about 450 kilometers.

A little later the electrification of the section of the Norwegian State Railway between Riksgransen and Narvik was completed. This section was commenced in 1921 and was finished in 1923. Electric trains accordingly can now be run from the Gulf of Bothnia to the Atlantic Ocean.

This line is not only well worth seeing by those interested in the technical side of the work, but presents also a great deal of exceedingly interesting scenery to the tourist. A journey from Stockholm by steamer to Lulea, thence by train via Boden and Kiruna to Narvik and then by steamer to Trondhjem and by rail through Jamtland to Stockholm is a most enjoyable summer trip and affords at the same time the opportunity of visiting one of the longest electrified lines in Europe.

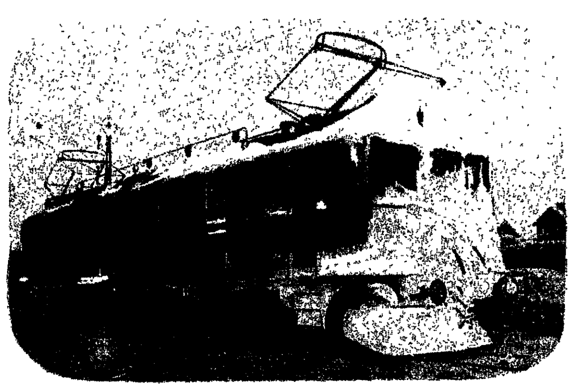


Fig. 3. An electric locomotive on the Riksgrans Railway after running under ordinary winter conditions.

THE ELECTRIFICATION OF THE DRAMMEN RAILWAY, NORWAY.

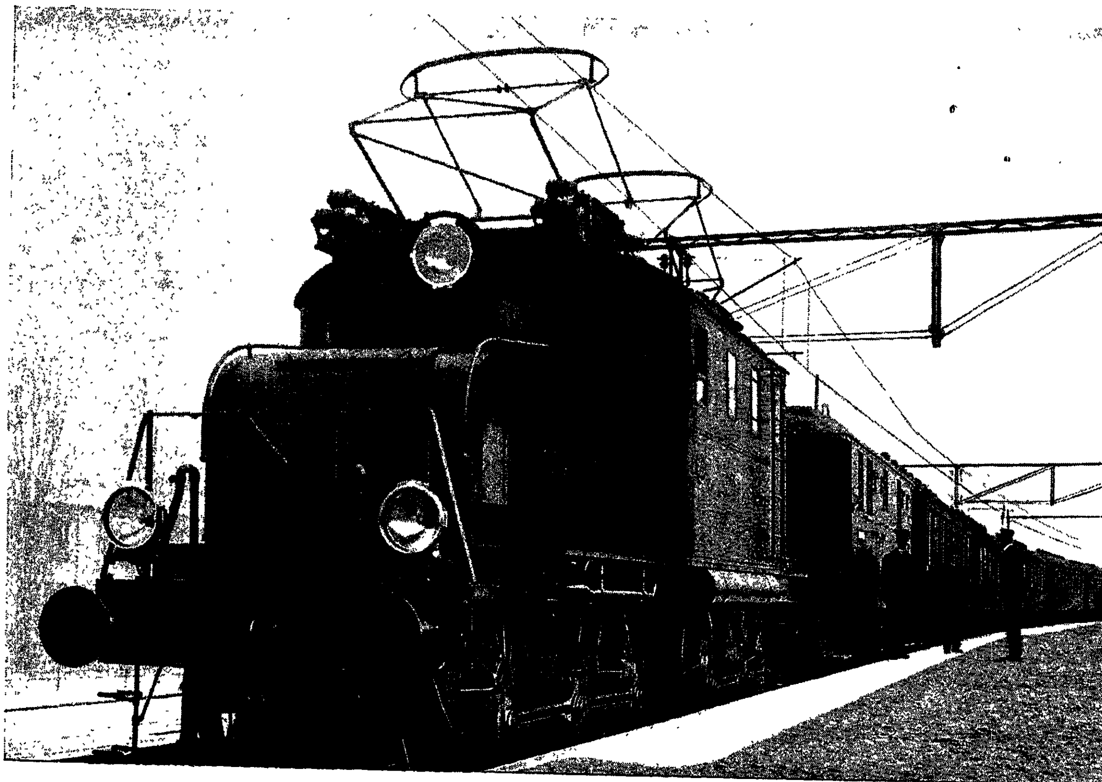


Fig. 1. Passenger train on the Drammen Railway, Norway,

The Drammen Railway, a narrow gauge line 53 kilometres in length running from Christiania to Drammen was opened for general traffic in 1872. Later on sections to Tonsberg, Larvik, Eidanger and Brevik were opened, and the whole line became generally known as the »Westbanen» (Western Railway). It is however rather as a line serving the suburbs of Christiania than as a section of the Western Railway that the Drammen Railway has of later years become of great importance. It became essential to rebuild the line for standard broad gauge traffic and also to double some of the track. Christiania by extending its suburbs in the districts served by the railway made the traffic increase to such an extent that it was necessary to lay double track over the sections nearest to Christiania, or to be exact, to Sandviken.

To further increase the carrying capacity of the line and also to enable it to serve as a link in the system of new standard gauge lines in the vicinity it was at the same time widened to the broad gauge. This change was decided on in 1910 and the work was begun in 1911.

The proposal to electrify the line was first made in 1912, but the system to be used only decided in 1916. The decision arrived at was to use single phase alternating current which would best lend itself to extensions.

A specification was then prepared covering the electrification including a substation and overhead equipment, as well as for the first 14 locomotives.

The tenders were submitted in the spring of 1918 and Asea's subsidiary company A/S Per Kure of Christiania secured the contract, in competition with German, Swiss, American and English firms, at the beginning of the summer of 1919, for the complete overhead equipment, substation, and 14 950 h.p. 4 + 4 electric locomotives. The value of this order reached a total of Kr. 1,000,000.

It was specified that the whole of the work was to be completed by the beginning of January 1922.

In 1920 a further order was obtained in competition with various well known firms for a further 8 electric locomotives of 4 + 4 type, making a total of 22 locomotives.

The work of erecting the poles for the trolley wire was carried out during the summer of 1919

and plans were made to complete the overhead line work for the section nearest to Christiania during the summer of 1920 and for the remaining sections in 1921. On account however, of the clashing of this work with other necessary changes to be carried out on the line and various unexpected difficulties in the supply of material the original plans could not be entirely carried out. In spite of the complicated nature of the overhead work and hindrances arising from various causes, the work was finished so that a trial run could be made over the section from Christiania to Asker during the first days of June and over the remaining section in October of the latter year.

Fig. 2. Map of the Drammen Railway.

On account of the various difficulties, chiefly those encountered in the civil engineering work, and late delivery of material, the hydro-electric power station could not be finished, so as to be able to supply energy before June in the same year, i. e. at the same time as the overhead line was finished.

The transformer substation also, on account of late delivery of the building material was as much delayed as the power station.

Regarding the locomotives, these too were somewhat delayed, chiefly on account of overdue delivery of the mechanical parts, but the first was ready for handing over about a month before the power station was ready to supply energy. When the trial runs could be carried out over the first section a sufficient number had been completed, and in October of that year the whole of the 14 locomotives covered by the first order were ready and delivery of the remaining 8 was made by the beginning of the next year.

On account of the conditions, the different parts of this installation including the power station, the overhead line, the substation and the locomotives were all somewhat late, but all to a similar extent, so that setting to work was not held up by the non-completion of any particular part.

Electric working was started in June over the section first completed and by August of that year all trains on the Christiania—Asker section were worked electrically.

Electric working on the further section Asker—Drammen was begun in August, and by October the whole line was operated entirely by electric locomotives.

This marked the completion of the original order. The electrification was carried out under particularly complicated conditions, as the line was at the same time being widened to standard gauge and the conditions of traffic made it necessary to run broad and narrow gauge trains at the same time during the change over.

The complete construction of the standard gauge line was finished by the end of the year and the narrow gauge trains accordingly were withdrawn from service. The whole of the installation has given great satisfaction in working, as also has the method devised by Asea for minimising the interfearance with telephone and telegraph lines.

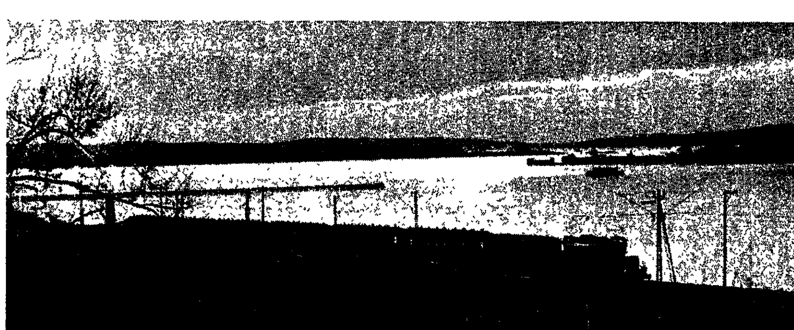


Fig. 3. Electric passenger train near Skarpsno.

ASEA'S NEW LOCOMOTIVES FOR THE RIKSGRANS RAILWAY.

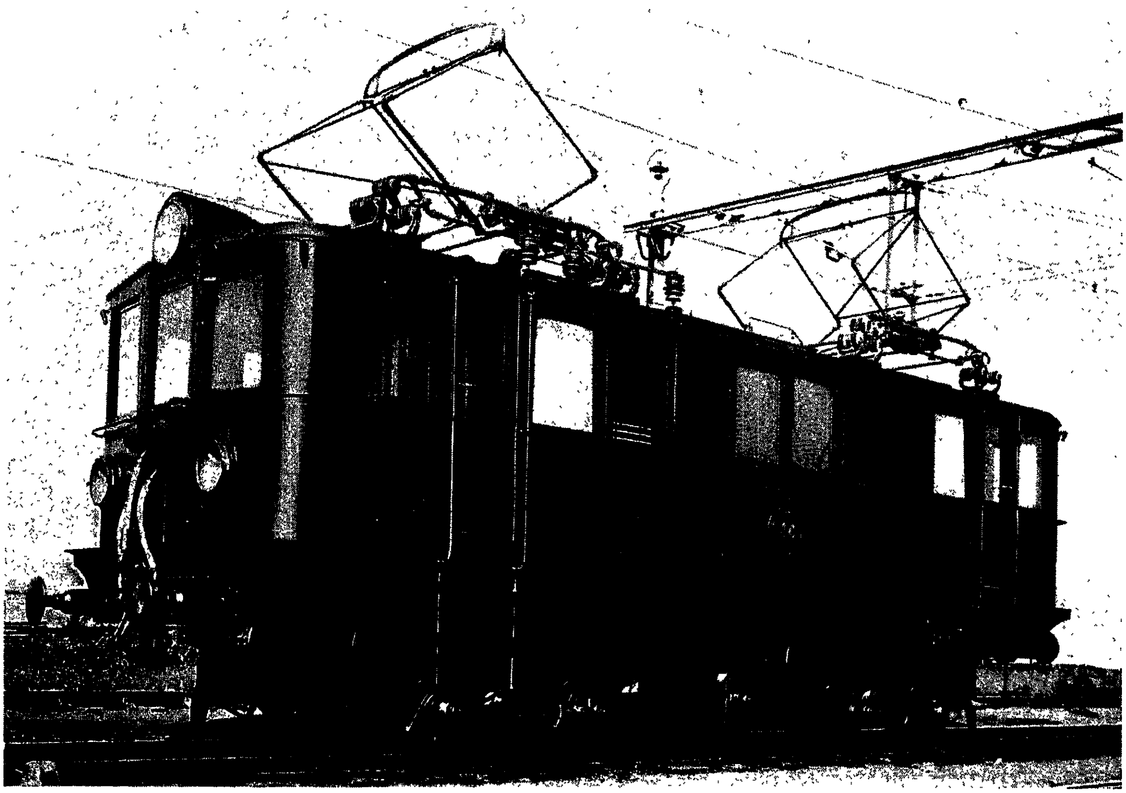


Fig. 1. Goods locomotive for the Riksgrans Railway, Sweden.

Goods locomotives, arrangement 0—8—0.

These locomotives, are primarily intended for goods traffic and are also used for shunting. The principal dimensions are:

Length over buffer beams, 11,250 m/m.
Fixed wheel base, 3,450 m/m.
Total wheel base, 6,350 m/m.
Diameter of driving wheels, 1,350 m/m.
Number of motors, 2.
Draw bar pull, continuously, about 6.2 tons, at a speed of 36 km per hour.
Draw bar pull, one hour, 9.5 tons, at 30.5 km per hour.
Draw bar pull, maximum, 18 tons.
Motor output continuous rating, 880 h.p.
Motor output, one hour, continuous rating, 1130 h.p.
Gear ratio: 3.82.
Maximum speed: 60 km per hour.
Weight of electrical equipment: 26.5 tons.
Weight of mechanical parts: 42.1 tons.
Total weight: 68.6 tons.

Fig. 1 is an exterior view of the locomotive. As will be seen the locomotive is arranged with four driving axles, which are driven by coupling rods from a lay shaft carried in bearings fixed in the main frames. Power is transmitted from the driving motors to the lay shaft through gearing mounted on each side of the motor. The first thing which strikes the eye is the powerfully designed slotted connecting rod between the inner pairs of wheels. This is necessary as the diameter of the wheels could not be made sufficiently large to use a connecting rod of standard pattern, although this was first suggested by Asea. The users however, could not agree to the greater length of locomotive, which would have resulted from this arrangement. The lay shaft centre accordingly had to be placed 110 m/m above the driving wheel centres and the slotted connecting rod construction could not be dispensed with. The clearance from the rail to the casing of the gear is 100 m/m and the distance between the lay shaft and the motor shaft centres is 840 m/m. The number of teeth in the larger gear wheels is 111 and in the pinion 29. The width of the gear wheels is 135 m/m.

To smooth out the power transmission through the connecting rods, and to minimise shocks set up during working, quill drive has been

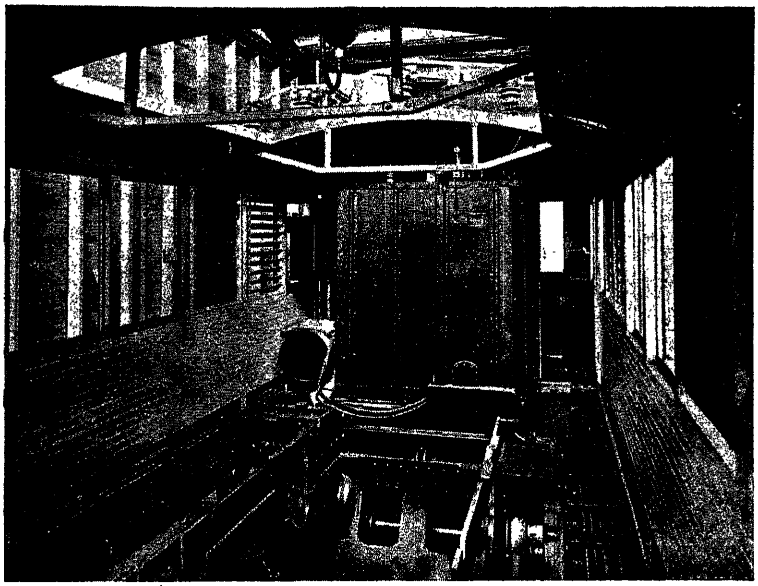


Fig. 2. Goods locomotive during erection.

adopted. The construction of this was found to be an exceedingly difficult matter on account of the small amount of space which was at the disposal of the designer. In principle the arrangement adopted consists of 6 radial laminated springs which transmit the power from the motor shaft to the gear pinion.

From the trolley wire the current is collected by two pantographs each furnished with a disconnecting link and is brought through a leading through insulator in the roof to the oil switch and thence to the high tension winding of the transformer.

The door of the oil switch cubicle is provided with a short circuiting arrangement which earths the high tension system when the door is opened.

The transformer is designed for a continuous output of 640 kVA and can be arranged with the following ratios: 14,000/120, 280, 480 and 720 volts. It is of shell type oil immersed and arranged for forced air cooling. The cooling air is obtained from a Schlotter ventilator and is passed through vertical pipes welded into the transformer tank. This system of cooling has proved exceedingly effective.

From the low tension terminals of the transformer the current is taken through conductors laid under the flooring to the relay panel, which carries the necessary contactors for the control, and thence through a reactance arranged in three sections to the motors.

The motors are forced cooled single phase commutator motors totally enclosed and carried direct in the locomotive main frames. The cooling air is obtained from an electrically driven double centrifugal ventilating fan mounted over the motors. They are permanently connected in series. The fields can be reversed by an electromagnetically operated reverser mounted over one of the motors.

The locomotive is furnished with a driving compartment at each end provided with controller and instruments, (voltmeter and ammeter, speedometer and vacuum gauge), hand operated air pump for raising the pantographs, and panel with switches and fuses for the lighting circuits. The machinery is housed in a roomy compartment in the centre, the two driving motors with the ventilators and reverser occupying a position in the middle of the locomotive. The transformer with the circuit breaker and the Schlotter ventilator is placed at one end, and the reactance coils, compresser and resistance are placed at the other end. Both sides of the body are furnished with louvres which permit very effective ventilation during running.

Fig. 2 shows the interior of the locomotive during erection and indicates the arrangement of the contacters and control leads.

Fig. 3 shows the interior of the machinery

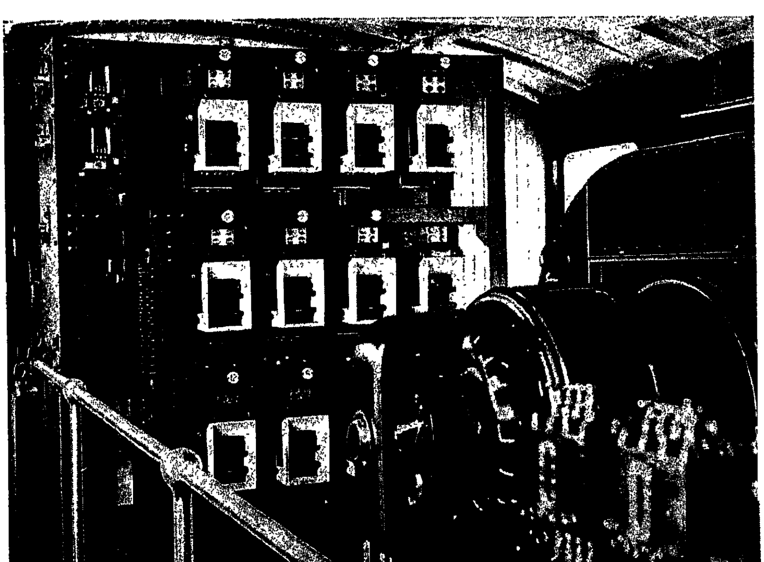


Fig. 3. Interior of goods locomotive.

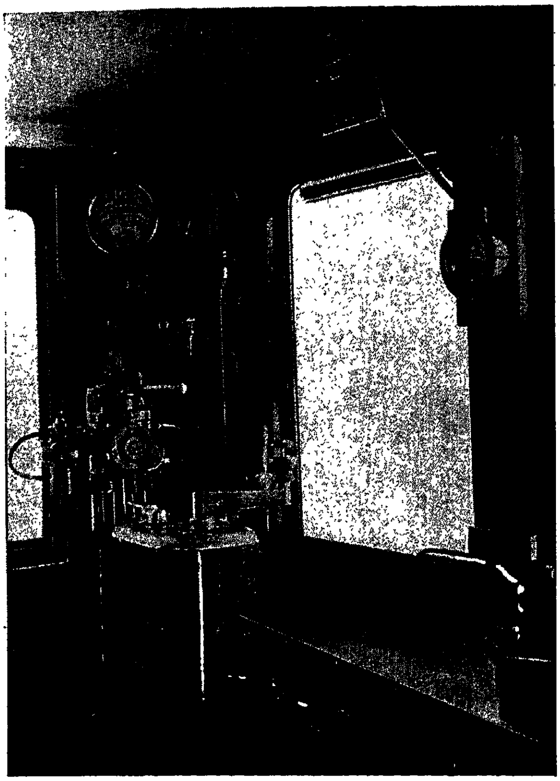


Fig. 4. Driver's compartment.

compartment and Fig. 4 one of the driver's compartments.

These locomotives have so far been used for ordinary traffic on the Southern Section of the line between Kiruna to Lulea. On account of the prevailing gradients easier conditions exist on this section than on the Northern Section from Kiruna to Riksgransen, as the loaded trains run down hill and only empties have to be hauled in the opposite direction. Locomotives normally capably of dealing with 14 ore trucks can accordingly handle about 30 on the Kiruna—Lulea section. The great weight of the trains handled has made it necessary however to construct the locomotives much stronger in all parts than is really justified by their specified capabilities. At the time of writing locomotives of this type have covered a mileage amounting to about 1,000,000 kilometers.

Passenger Locomotives, Type 4—4+4—4.

These locomotives which were specially designed for dealing with the passenger traffic between Lulea and Riksgransen are constructed as two close coupled units, both halves being precisely similar in their mechanical and electrical details. Each locomotive half is provided with two driving motors, driving through gearing on to a common lay shaft from which the power is transmitted to the driving wheels by connecting rods. The arrangement is almost entirely similar to that adopted for the goods locomotives, with the difference that the centres of the driving wheels and the lay shaft are at the same height above the rail level, an arrangement which has made it possible to use connecting rods of ordinary standard pattern in place of the slotted coupling rod used in the goods locomotive.

Fig. 7 shows one of the locomotives which has just left the erecting shops. Each unit of the locomotive has two pairs of driving wheels with bearings in the main frames and a four wheeled bogie. With this arrangement the locomotive negotiates curves very comfortably and is well suited to high running speeds. These characteristics have been fully proved in practice and the locomotive runs exceedingly smoothly and steadilly even at the highest speeds. The principal dimensions are as follows:

Length over buffer beams: 21,400 mm (approx. 70').

Fixed wheel base: 3,450 m/m.

Total wheel base: 16,200 m/m.

Diameter of driving wheels: 1,350 m/m.

Number of motors: 4.

Draw bar pull continuous rating: 5.7 tons at 78 km per hour.

Draw bar pull one hour rating: 8.8 tons at 66 km per hour.

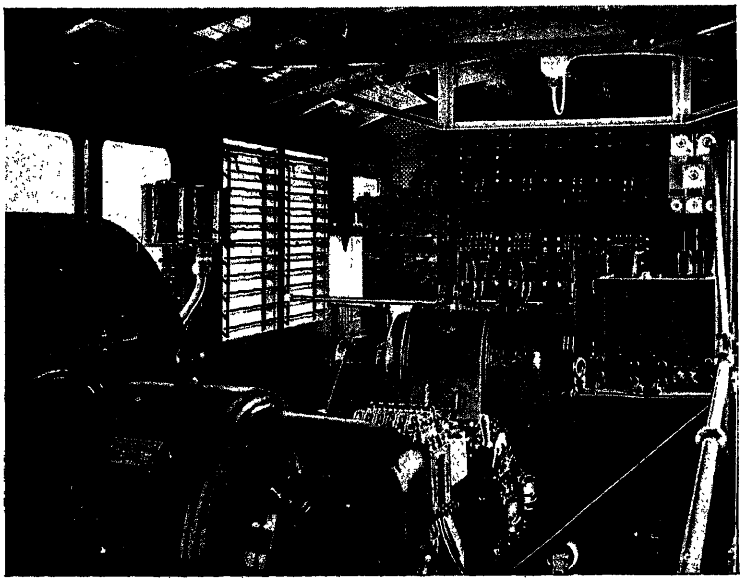


Fig. 5. Interior of express locomotive.

Maximum draw bar pull 16 tons.

Motor output continuous rating: 1,760 h.p.

Motor output one hour rating: 2,260 h.p.

Gear ratio: 1.76.

Maximum speed: 100 km per hour.

Weight of electrical equipment: 52.6 tons.

Weight of mechanical parts: 70.6 tons.

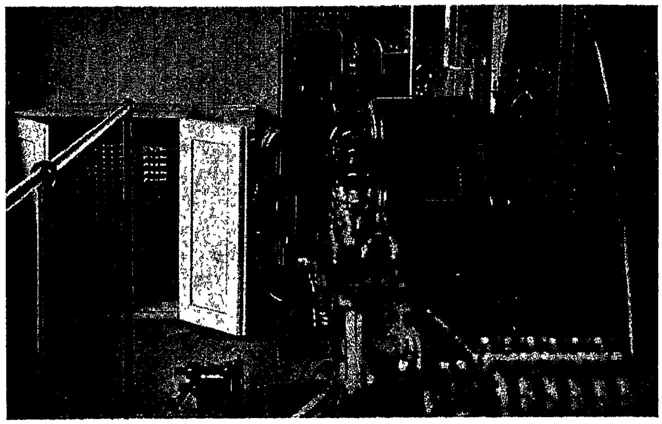


Fig. 6. Interior of express locomotive, another view.

Total weight: 123.2 tons.

Each locomotive half is arranged on the same principle as the goods locomotives already described except that the driving cab at one end is dispensed with. This has made more space available and has enabled the auxiliary machinery and apparatus to be better arranged.

Fig. 5 is an interior view taken from the close coupled end of the locomotive. In the background nearest to the driving cab is placed the main transformer. From this current is taken in solid copper strip conducters direct to the main switch and thence under the flooring to the regulating transformers and motors. The air compresser is placed in the centre of the machinery compartment by the side of the regulating transformers. All the conducters are in this way exceedingly well protected and their length is as short as is practically possible.

The machinery compartment generally gives the impression of being light, roomy and straightforwardly arranged, which is a feature of the greatest importance in an electric locomotive, which is so dependent on the accurate adjustment of its many complicated pieces of apparatus. Fig. 6 is another view of the machinery compartment in which the second close coupled locomotive half can be seen through the connecting door.

Against the end wall can be seen the connections for the multiple unit control leads. From this connection board conductors are taken to multiple coupling boxes and from these in leather armoured tubes to the other half of the locomotive. The coupling boxes can be connected and disconnected by using the single hand grip provided. No transmission of low tension current takes place between the two locomotive halves, as they are independently equipped and each half is complete in itself. The high tension systems are however connected together by insulated conducters and flexible couplings arranged above the roof. The driving cabs are arranged in the same way as in the case of the goods locomotives. An addition is an ammeter for checking the current taken by the motors in the farther locomotive half.

Locomotives of this type have at the time of writing covered a mileage of about 250,000 kilometers and have worked faultlessly. The mechanical parts, both for the goods and the passenger locomotives were supplied by A.-B. Svenska Jarnvagsverkstaderna, (The Swedish Railway Works Ltd.) of Falun.

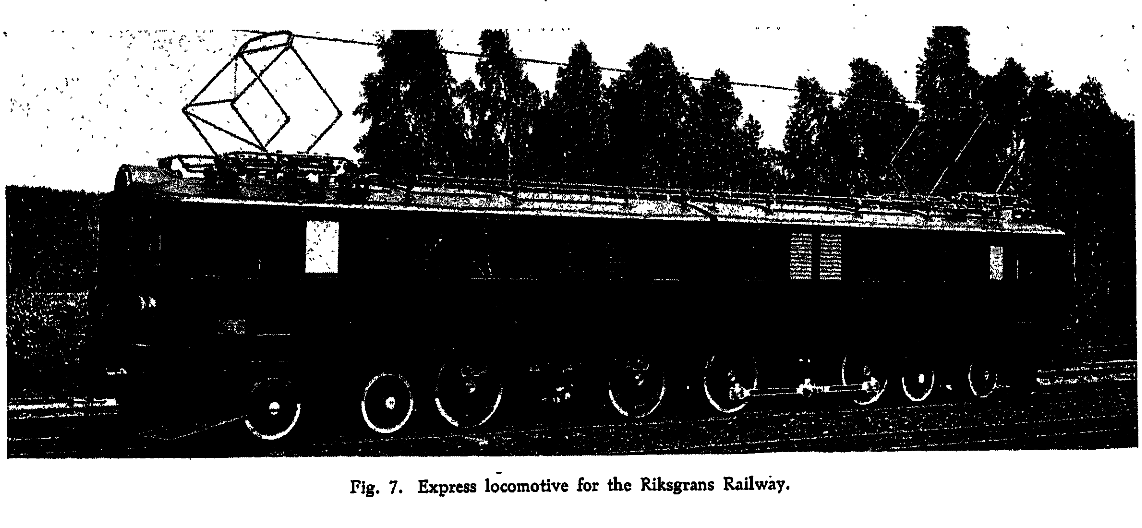


Fig. 7. Express locomotive for the Riksgrans Railway.

THE ELECTRIFICATION OF THE STOCKHOLM—GOTHENBURG SECTION OF THE SWEDISH STATE RAILWAYS.

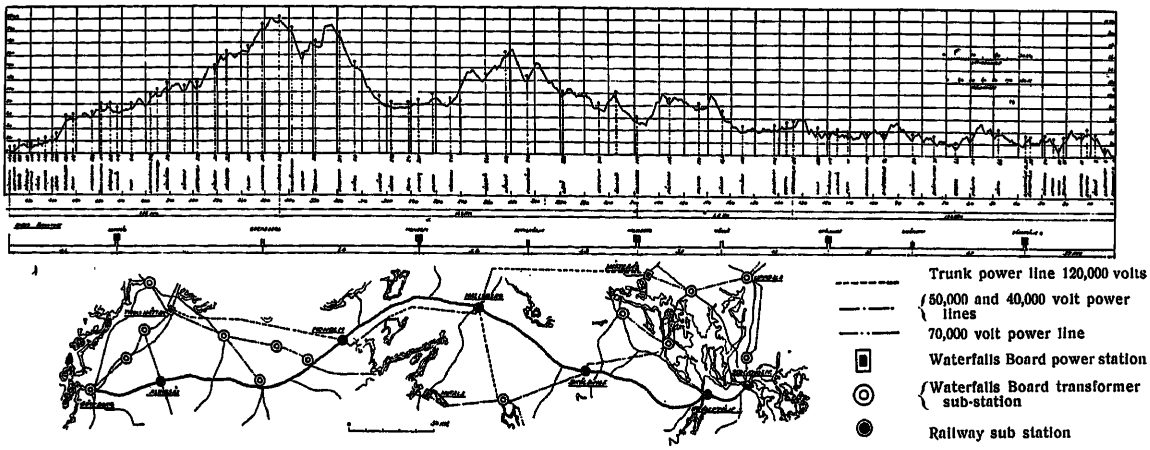


Fig. 1. Profile and map of the line.

At the request of H.R.H. the King of Sweden the Swedish State Railways Board submitted in February 1920 prices and estimates for the continuation of the electrification of the State Railways, together with detailed proposals for the electrification of the line from Stockholm to Gothenburg. On the 19th March of the same year this proposal was placed before the Riksdag covering the electrification of the above section of the line with single phase alternating current generated in hydroelectric power stations and requiring a capital expenditure of 23,000,000 kr. The scheme was generally approved.

The Telegraphs Department however, submitted that the problems regarding disturbances on the telephone and telegraph lines had not been cleared up in a satisfactory manner and the Riksdag accordingly definitely refused to allow the electrification to be proceeded with until such time as this question should be properly settled.

Following this decision a Royal Commission was appointed and given instructions to investigate the problem as quickly as possible and to submit proposals regarding the measures to be taken to overcome the interfearance in question.

At the same time the Swedish Waterfalls Board asserted that certain advantages could be attained by taking the power necessary for working the line from the existing three phase network and converting it to single phase.

Accordingly on the 11th June 1920 a further Royal Commission was appointed with instructions to investigate suitable means for transmitting electrical energy from the available power stations to the railway.

On the 31st March 1922 the same Commission were instructed to investigate the various economic and technical advantages which would be obtained by electrifying the State Railways with continuous current.

The first Commission submitted their report on the 31st December 1922 the substance of which was that the telephone and telegraph line disturbances caused by single phase traction could be reduced to a negligable value by taking the following precautionary measures:

1) Transferring all the overhead telegraph and telephone lines from positions alongside the railway to main roads or replacing them with cable having earthed sheath and iron armouring.

2) Providing the contact line wire with a return wire of copper and placing booster transformers at suitable intervals.

3) Having the generators and motors designed as far as possible free from high frequency harmonics.

For electrification with continuous current the following main precautions were recommended:

1) Transferring all overhead telegraph and telephone lines to the main roads.

2) Providing the contact line wire and also the return line with a necessary number of feeders to prevent earth currents, which mainly effect telegraph and telephone apparatus and give rise to electrolysis.

3) Generators and motors to be in the highest possible degree free from high frequency harmonics.

The second Commission submitted their report on the 30th June 1923, the following being the main results:

1) The power necessary for running the railways could be taken from the existing three phase system with frequencies of 50 and 25 cycles and could be converted in substations along the railway line to single phase alternating current or continuous current, whichever should prove most economical, when all questions were taken into account.

2) Electrification with continuous current had not been found to be technically more advantageous or economical than electrification with single phase, so that as the former Commission had reported that a satisfactory solution of the problem of telephone disturbances could be arrived at in the case of single phase traction by the adoption of certain precautions, there appeared to be no reason why this system should not be used, especially as several years experience with it had been obtained in the country.

After consideration of the reports of both Commissions the Swedish State Railways Board, on the 7th May 1923 sought to obtain powers for carrying out the work on the lines suggested and the Royal Assent was given to this on the 15th June 1923.

Accordingly the line, which has a total length of 460 km and a maximum gradient of 1 in 100 is being electrified on the single phase system, energy being supplied at 15,000 volts $16^{2}/_{3}$ cycles from five converter substations furnished with the following:

Sodertelje	3	motor	converters	each	2,400 kVA
Skoldinge	2	,,	,,	,,	,, ,,
Hallsberg	2	,,	,,	,,	,, ,,
Moholm	2	,,	,,	,,	,, ,,
Alingsas	3	,,	,,	,,	,, ,,

Each converter station supplies its own section of trolley wire of from 80 to 125 km in length, so that the converter stations do not work in parallel on the 15,000 volt side. The map reproduced in fig. 1 shows the route taken by the line and the positions of the converter substations.

The system of trolley wire suspension is generally similar to that used on the Riksgrans Railway with the addition however of copper return conductors. Fig. 2 shows the suspension arrangement for the trolley wire.

As a commencement the locomotive stock will consist of 50 coupled locomotives type 2—6—2, the general arrangement being as shown in fig. 4. The leading dimensions of the locomotives are:

Length over buffer beams	13,000 m/m.
Fixed wheel base	5,400 ,,
Total wheel base	9,400 ,,
Diameter of driving wheels	1,530 ,,
Diameter of leading wheels	970 ,,
Number of motors	2

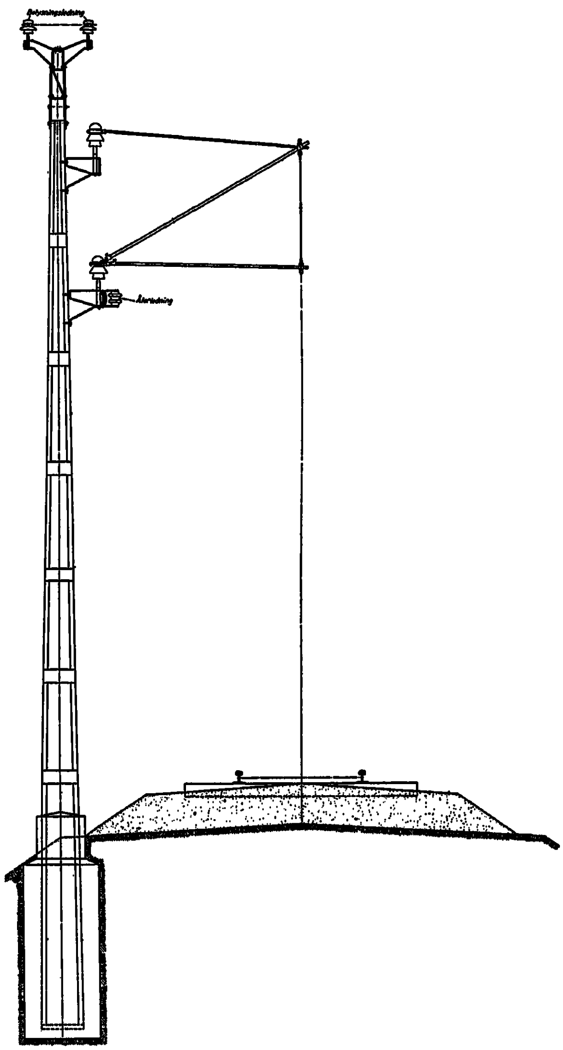


Fig. 2 a. Standard pole for supporting trolley wire.

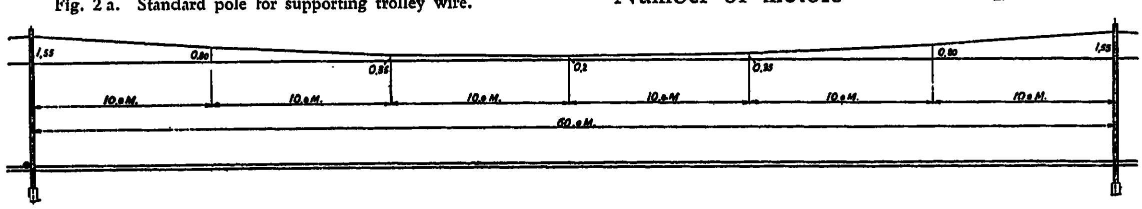


Fig. 2 b. Trolley wire suspension.

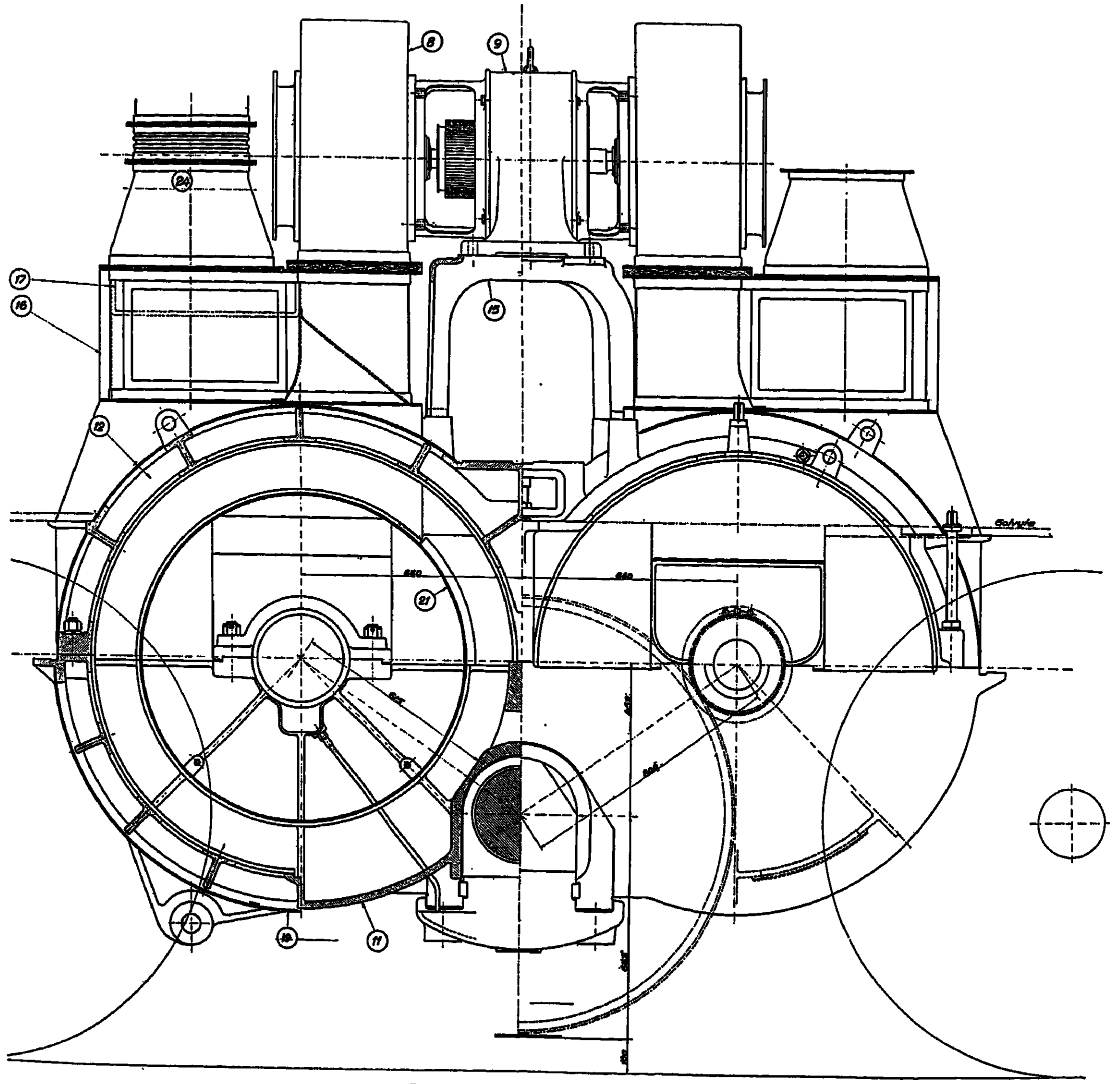


Fig. 3. Drives, motors and lay shaft.

Motor output, continuous 1,350 h.p.
Motor output, one hour 1,660 „
Adhesive weight 51 tons.
Total weight 78.5 „

The locomotives are being supplied with different gear ratios, the lower for passenger service and the higher for goods service.

The data for the goods locomotives are as below:

Train weight maximum 900 tons.
Draw bar pull, continuously 6,200 kgs.
Draw bar pull, one hour 8,700 „
Draw bar pull, maximum 13,500 „
Speed at continuous output 57.5 km per hour.
Speed at one hour output 49.5 km per hour.
Speed, maximum, 67 km per hour.

The corresponding data for the passenger locomotives are:

Weight of train maximum 500 tons.
Draw bar pull, continuous 4,700 kgs.
Draw bar pull, one hour 6,600 „
Draw bar pull, maximum 12,500 „
Speed with continuous output about 76.5 km per hour.
Speed with one hour output 65.5 km per hour.
Speed, maximum, 90 km per hour.

Fig. 3 shows the driving motors and lay shaft and indicates how the motors and the auxiliary driving axle are carried in a steel housing which is bolted up to the frames to which it acts as a cross stay.

The stators and brush rockers for the two motors are firmly held in a steel housing, which is common to both machines. The rotors are carried in separate bearings which are supported by the housing. The motor shafts are furnished at both ends with quill driven pinions, which

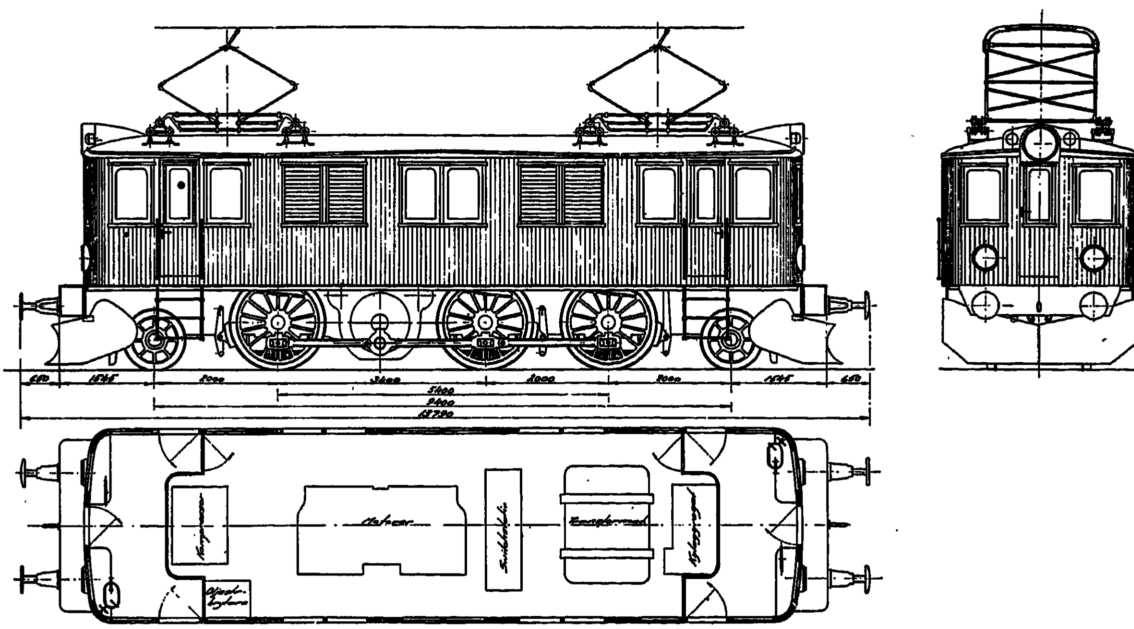


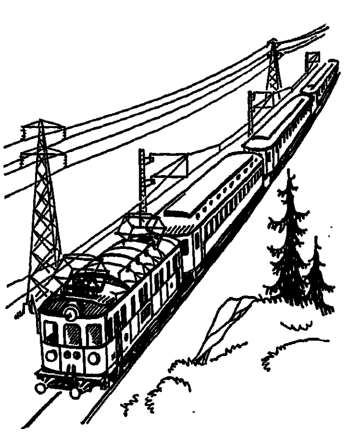
Fig. 4. Locomotive type 2—6—2.

drive on to gear wheels on the lay shaft. The lay shaft is provided with cranks and crank pins for the coupling rods.

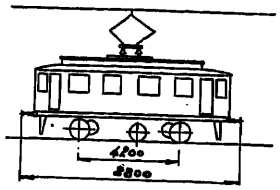
The control gear and transformers are of the same construction which has previously been used in the locomotives of types Od and Of. The mechanical parts generally will be of the most solid construction. The bodies will be furnished with double walls and finished outside with teak.

The Swedish State Railway Board have just recently placed an order with Asea for the electrical equipment for all five substations. The delivery of the fifty electric locomotives has been entrusted by the Railway Board to Asea and A.-B. Svenska Jarnvagsverkstaderna, (The Swedish Railway Works Ltd.) Falun, A.-B. Lindholmen—Motala, Motala and Nydqvist & Holm A.-B., Trollhattan.

Delivery is to be completed by the end of 1925.

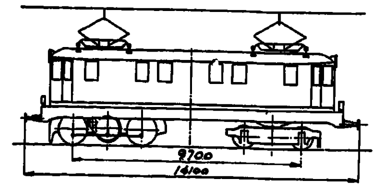


Principal data of ASEA locomo



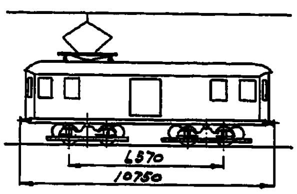
Type 2—2—2.

Name of railroad: Mellersta Ostergotland Ry, Sweden.
Date: 1908.
Number delivered: 1.
Total weight: 12 tons.
Diam. driving wheels: 800 mm.
Diam. running wheels: 740 mm.
Current system: A.C. Single phase, 10,000 volts, 25 cycles.
Number of motors: 2.
One hour h.p. rating: 36.
Maximum speed: 40 km p. h.



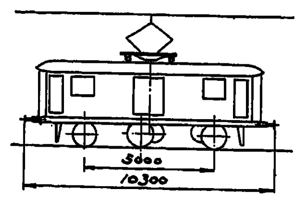
Type 0-4-4.

Name of railroad: Swedish State Ry:s.
Date: 1908.
Number delivered: 1.
Total weight: 52.2 tons.
Diam. driving wheels: 1,350 mm.
Diam. running wheels: 870 mm.
Current system: A. C. Single phase 15,000 volts, 15 cycles.
Number of motors: 2.
One hour h.p. rating: 450.
Max. speed: 75 km p. h.



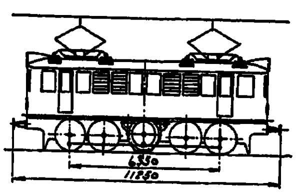
Type 0—4+4—0.

Name of railroad: Mellersta Ostergotland Ry, Sweden.
Date: 1915.
Number delivered: 4.
Total weight: 22.4 ton.
Diam. driving wheels: 800 mm.
Current system: A. C. Single phase 10,000 volts, 25 cycles.
Number of motors: 4.
One hour h.p. rating: 140.
Max. speed: 40 km p. h.



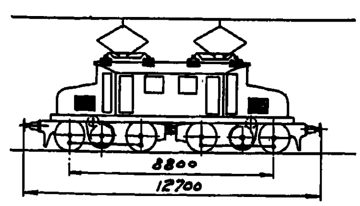
Type 2—4—0.

Name of railroad: Lund Bjarred Ry, Sweden.
Date: 1916.
Number delivered: 1.
Total weight: 26.1 tons.
Diam. driving wheels: 1,000 mm.
Diam. running wheels: 1,000 mm.
Current system: A. C. Single phase 16,000 volts, 15 cycles.
Number of motors: 2.
One hour h.p. rating: 230.
Max. speed: 60 km p. h.



Type 0—8—0.

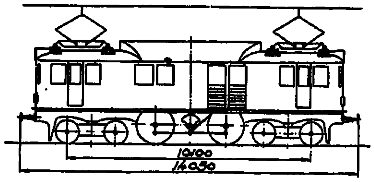
Name of railroad: Swedish State Ry:s.
Date: 1919—1922.
Number delivered: 10.
Total weight: 68.5 tons.
Diam. driving wheels: 1,350 mm.
Current system A. C. Single phase, 15,000 volts, 15 cycles.
Number of motors: 2.
One hour h.p. rating: 1,130.
Max. speed: 60 km p. h.



Type 0—4+4—0.

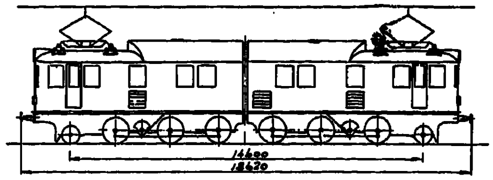
Name of railroad: Norwegian State Ry:s.
Date: 1919—1923.
Number delivered: 22.
Total weight: 64 tons.
Diam. driving wheels: 1,445 mm.
Current system: A. C. Single phase, 15,000 volts, 15 cycles.
Number of motors: 2.
One hour h.p. rating: 940.
Max. speed: 60 km p. h.

tives A.C., Single phase system.



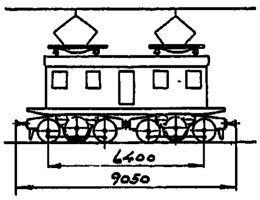
Type 4—4—4.

Name of railroad: Swedish State Ry:s.
Date: 1911—1915.
Number delivered: 2.
Total weight: 90 tons.
Diam. driving wheels: 1,575 mm.
Diam. running wheels: 870 mm.
Current system: A. C. Single phase 15,000 volts, 15 cycles.
Number of motors: 1.
One hour h.p. rating: 1,000.
Max. speed: 100 km p. h.



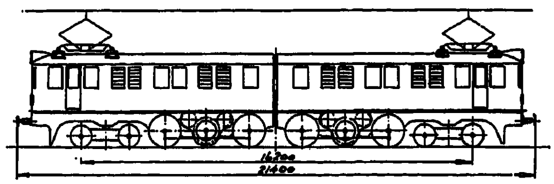
Type 2—6+6—2.

Name of railroad: Swedish State Ry:s.
Date: 1911—1915.
Number delivered: 6.
Total weight: 138 tons.
Diam. driving wheels: 1,100 mm.
Diam. running wheels: 730 mm.
Current system: A. C. Single phase 15,000 volts, 15 cycles.
Number of motors: 2.
One hour h.p. rating: 1,600.
Max. speed: 60 km p. h.



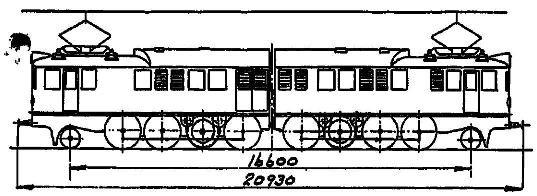
Type 0—4+4—0.

Name of railroad: Thamshavn Ry, Norway.
Date: 1918.
Number delivered: 2.
Total weight: 42 tons.
Diam. driving wheels: 1,000 mm.
Current system: A. C. Single phase 7,000 volts, 25 cycles.
Number of motors: 4.
One hour h.p. rating: 560.
Max. speed: 50 km p. h.



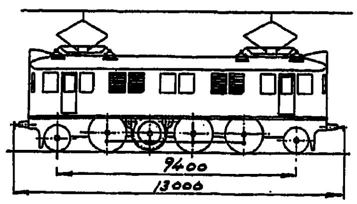
Type 4—4+4—4.

Name of railroad: Swedish State Ry:s.
Date: 1919—1922.
Number delivered: 2.
Total weight: 123.3 tons.
Diam. driving wheels: 1,350 mm.
Diam. running wheels: 960 mm.
Current system: A.C. Single phase, 15,000 volts, 15 cycles.
Number of motors: 4.
One hour h.p. rating: 2,260.
Max. speed: 100 km p. h.



Type 2—6+6—2.

Name of railroad: Swedish State Ry:s.
Number in course of erection: 5.
Total weight: 130 tons.
Diam. driving wheels: 1,530 mm.
Diam. running wheels: 850 mm.
Current system: A. C. Single phase 15,000 volts, 15 cycles.
Number of motors: 4.
One hour h.p. rating: 2,900.
Max. speed: 60 km p. h.



Type 2—6—2.

Name of railroad: Swedish State Ry:s.
Number in course of erection: 50.
Total weight: 78.5 tons.
Diam. driving wheels: 1,530 mm.
Diam. running wheels: 970 mm.
Current system: A.C. Single phase 15,000 volts, 16.7 cycles.
Number of motors: 2.
One hour h.p. rating, 1,660.
Max. speed passenger service: 90 km p. h.
Max. speed freight service: 60 km p. h.

Vesteras 1924, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

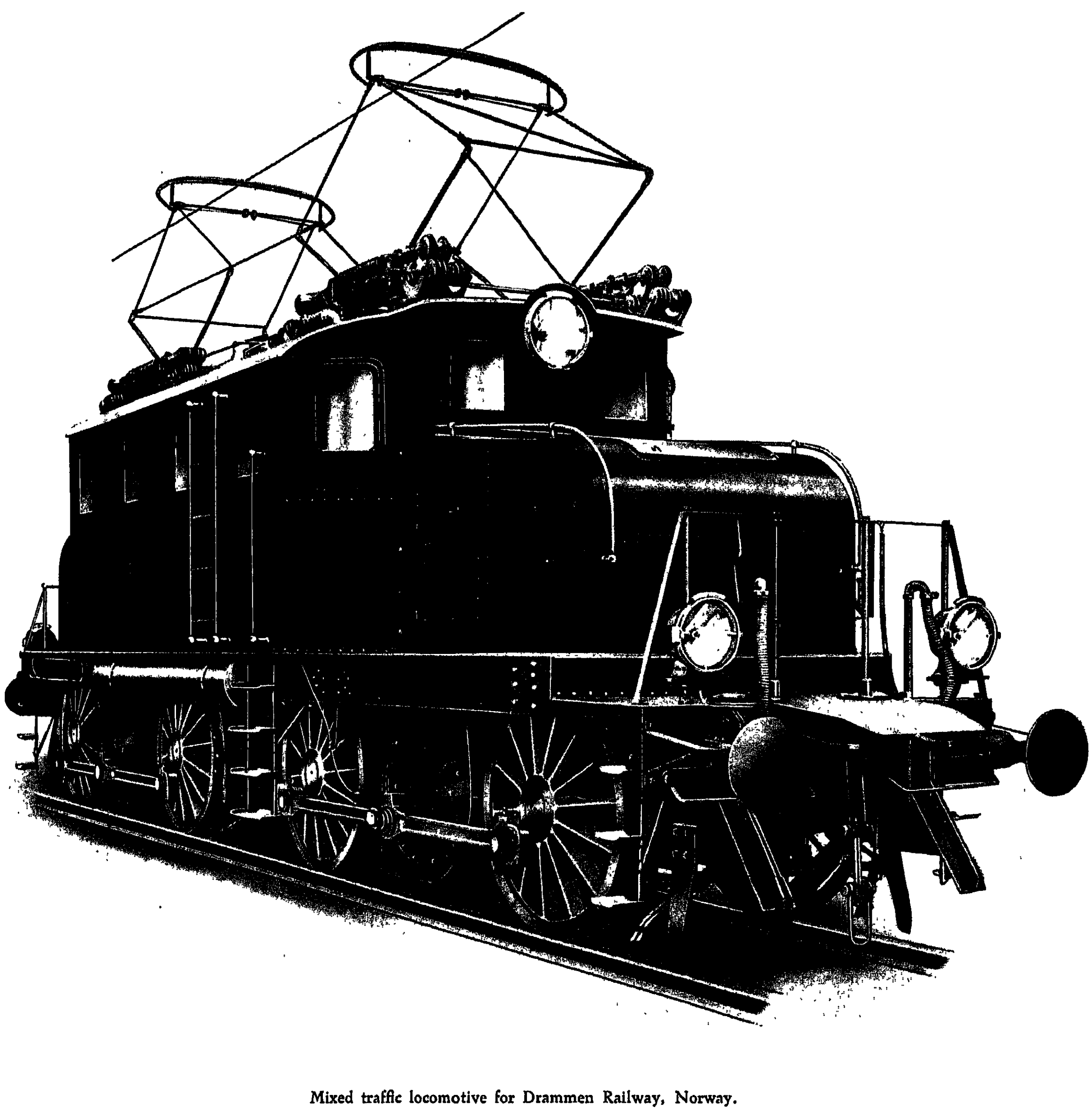
ALLMÄNNA SVENSKA ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL ELECTRIC LTD
5, CHANCERY LANE—LONDON

JULY

All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesterås, Sweden.
Permission is given to reprint articles or extracts from this journal, on condition that the name — Asea-Journal — is clearly stated.

1924



Mixed traffic locomotive for Drammen Railway, Norway.

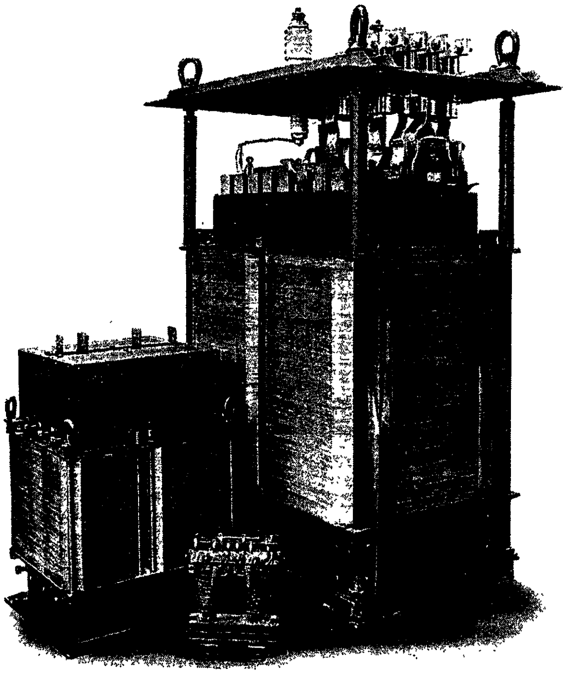


Fig. 4. Transformers.

no drawback, such as slipping of the driving wheels of one bogie, has occured in practice.

The motors are totally enclosed and have 6 inspection covers located round the commutator for attending to the commutator and brush gear. These are easy of access through inspection covers placed in the sheet steel bonnets over the motors. A motor driven ventilator is placed directly over each motor and blows cooling air through it.

Fig. 5 is an end view of the locomotive with the bonnet over the motors lifted off. The motors are supported in the bogie frames by cylindrical bearers. This arrangement ensures that the axis of the motors are always directly parallel to the lay shaft and also that the correct centre distance shall be maintained between them, which is essential for the satisfactory running of the gear. The motors can also be arranged well down in the bogie frame and can if required be easily removed and replaced.

As regards the control system of the locomotive the arrangements which are provided have already been indicated in the description of the driver's compartment. The main controller operates the electro-magnetic contacters on the relay panel and also works the electro-magnetic reverser (which changes the direction of the current in the driving motor's field windings relatively to the rotor current) for reversing the locomotive. For operating the controls alternating current at 210 volts is used and taken direct from the main transformer.

The number of running positions is 17. The pressure supplied to the motors in the first position is 72 volts (for each motor) and increases successively to 358 volts in the 17th position, all reckoned with a trolley wire voltage of 15,000. The highest running position is only intended for use when the line voltage is particularly low and under normal conditions is seldom required. The voltage increase from one step to another has been made greater for the last positions than for the first and the voltage graduation provided at starting has proved to be particularly suitable for varying train loads and track conditions.

Brakes etc.

The locomotive is provided with the vacuum brake. Two rotary vacuum pumps are used each driven by its own motor. The smaller runs continuously to maintain the vacuum in the train pipe and to compensate for the leakage which takes place. The larger pump runs only if the brakes have been applied and is of sufficient dimensions to bring up the vacuum quickly to its normal value, to enable the brakes to be released. Both pumps are worked by the brake controller handle, which also admits air to the train pipe when the brakes are to be used.

Compressed air for the sand apparatus, the whistle, and the pantographs is supplied by a motor compressor of rotary type like the vacuum pumps. The compresser which is shown in fig. 5 close to the driving motor is arranged with the usual type of automatic regulating apparatus, which maintains the air pressure at a value between 5 and 7 atmospheres.

For lighting the locomotive and also for the head and tail lamps alternating current at 32 volts is used. If the pressure on the trolley wire should fail an accumulator battery is automatically connected to the circuit. As the voltage of the lamps is so low (from which it follows that the filaments are relatively thick) the fluctuations in the light are scarcely noticeable with the 15 cycle current. For lighting purposes a special small transformer is provided.

For heating the coaches of passenger trains provision has been made for the supply of 200 kW from the main transformer of the locomotive at 478 volts. From the transformer terminals leads are run to an electrically operated switch in the transformer compartment and thence to couplings, two at each end of the locomotive fixed on the buffer boards. Two cables have been used in parallel between the locomotives and coaches and between the coaches themselves to make the couplings as light and easily handled as possible. The main switch for this circuit

is operated from a small tumbler switch in one of the driving cabs.

Trial runs were made with these locomotives on the section between Christiania and Asker in May 1922. They were driven day and night drawing trains of 300 tons between Christiania and Sandviken and were found fully up to their specification. Tests were also carried out with a train of 500 tons on a bank of 16 per 1,000 between Lier and Spikkestad and on this grade a speed of 13 km per hour was attained without difficulty. In June the first two locomotives were taken over for regular traffic service between Christiania and Asker and thereafter steam locomotives were successively displaced as electric locomotives became available, and as soon as drivers could be trained and made fully acquainted with their construction and working.

By the middle of July the whole of the local train service to Sandviken was worked electrically. After this goods and passenger traffic between Christiania and Drammen was as a commencement worked electrically as far as Heggedal (the next station to Asker), where the electric was changed for a steam locomotive. From the first, passenger traffic was run electrically, the locomotives being particularly suitable for the two services on account of their good performance at both maximum and medium speeds. The silent running of the locomotives at varying speeds is particularly noteworthy. The bogie arrangement employed has proved itself particularly suitable to the conditions obtaining.

Lastly it should be recorded that the machines have proved entirely satisfactory when used on service of very varying character including fast passenger, local and goods services. The working costs during the time that traffic has been worked electrically have shown that the adoption of this type of locomotive, and the selection of the various apparatus used in connection with it, was most fortunate, for both electrical and mechanical parts have not been found wanting in any demands made upon them.

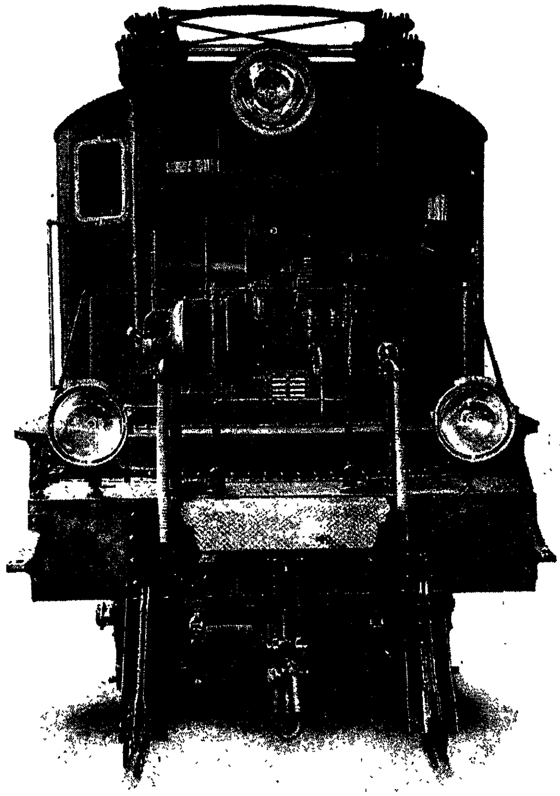


Fig. 5. End view of locomotive.

The mechanical parts of the locomotives were supplied by A/S Norsk Maskinindustri, Christiania.

MOTORS FOR 0—8—0 AND 4—4+4—4 LOCOMOTIVES FOR THE RIKSGRANS RAILWAY AND FOR 0—4+4—0 LOCOMOTIVES FOR THE DRAMMEN RAILWAY.

In the foregoing articles the different types of locomotives have been described which have been recently delivered by Asea for the Swedish and Norwegian State Railways. In general these locomotives have been equipped with two motors each, an exception being the locomotives of 4—4+4—4 type which being intended for heavy express traffic were necessarily of greater power and were provided with 4 motors. By adopting this arrangement it was possible to use the same motor type for both the 0—8—0 and 4—4+4—4 locomotives and thus only two different motor types were necessary in executing these important orders.

To begin with, and for the sake of comparison, a table is given below setting forth the principal details for the motors.

Periods	Locomotive type	Max. speed km per hour	No. of motors	No. of poles	1 hour rating of motor h.p.	Continuous rating of motor h.p.	Gear ratio	Driving wheel diameter	Tractive effort 1 hour rating tons	Maximum tractive effort tons	Speed at 1 hour rating km pr hour
15	0—4+4—0	60	2	12	470	400	4.27	1,445	7.2	16	33.5
15	0—8—0	60	2	14	565	450	3.82	1,350	9.5	18	30.5
15	4—4+4—4	100	4	14	565	450	1.76	1,350	8.75	16.5	66

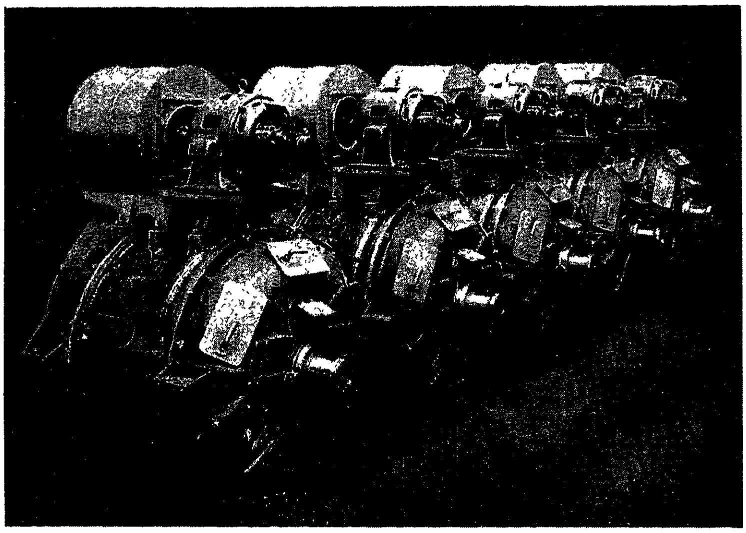


Fig. 1. Motors of type SJ 1103 with fans mounted.

The two motor types are designed in exactly the same manner. They are plain series motors with compensating and commutating windings and generally similar to most of the modern single phase motors. The mechanical design is also generally the same for both types, except for alterations which are involved by a somewhat different manner of fixing in the locomotives. Fig. 5 shows the smaller type in side elevation and section.

In a locomotive motor as much attention must be given to the mechanical parts as to the electrical, as on account of the vibrations and shocks which arise strains are set up which are more or less impossible to forecast. It is therefore of importance that the calculated strains should be kept low and that only material with a high elastic limit is used for those parts which are most exposed to such shocks. This point has been kept in mind in the construction of the motors and an idea can be gathered from fig. 5 of the strong mechanical construction. It may be stated further, that with the exception of the active iron, only steel has been used in both stator and rotor, the axles being of nickel steel. No cast iron whatever has been employed. Figs. 1 and 2 show the two types of motor as they appear and partly erected in the shops. As regards active iron and windings the stator and rotor cores are laminated, the stator being furnished with definite poles and the windings are to a considerable degree placed similarly to those of a continuous current machine with commutating poles and compensating winding. The rotor winding is a parallel winding with equalising connections and is soldered directly into the commutator segments without the use of special commutator risers or high resistance connections. By this method a particularly strong and simple construction has been obtained.

In order to ensure good commutation the commutating field must have a definite strength and phase, partly in order to compensate the reactance voltage (tending to cause circulating currents), and partly to compensate the induced voltage due to transformer effect in the short circuited coils, which is caused by pulsations in the main field. The former can be looked upon as being in phase with the armature current, while the last lags by about 90°, so that the commutating field must have a

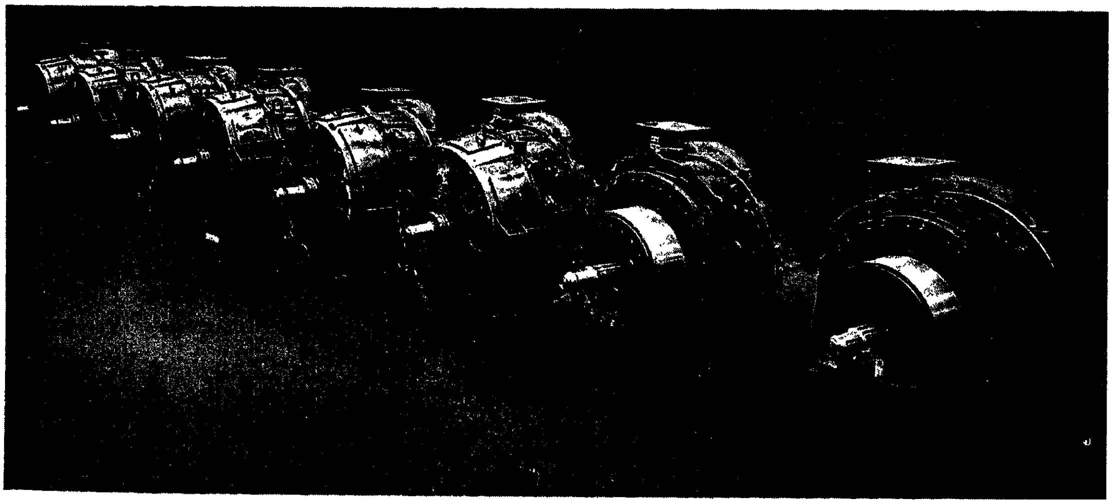


Fig. 2. Motors type SJ 1303.

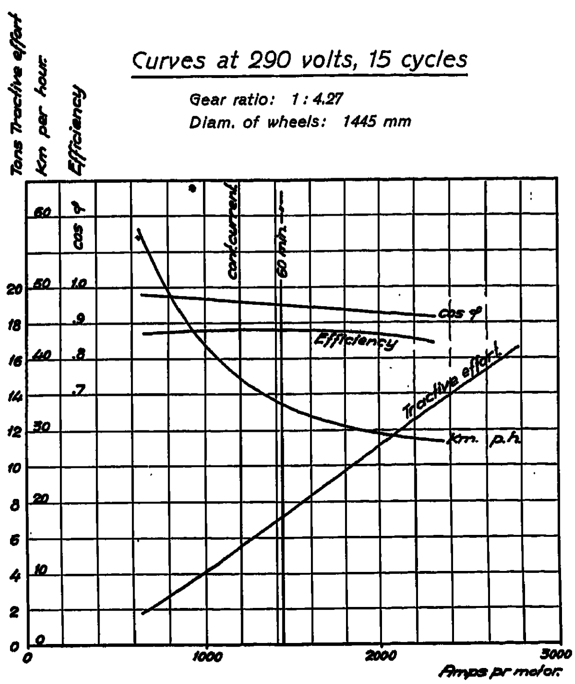


Fig. 3. Mixed traffic locomotive arrangement 0—4+4—0 with two motors type SJ 1103, 470 h.p., 520 r.p.m., 15 cycles.

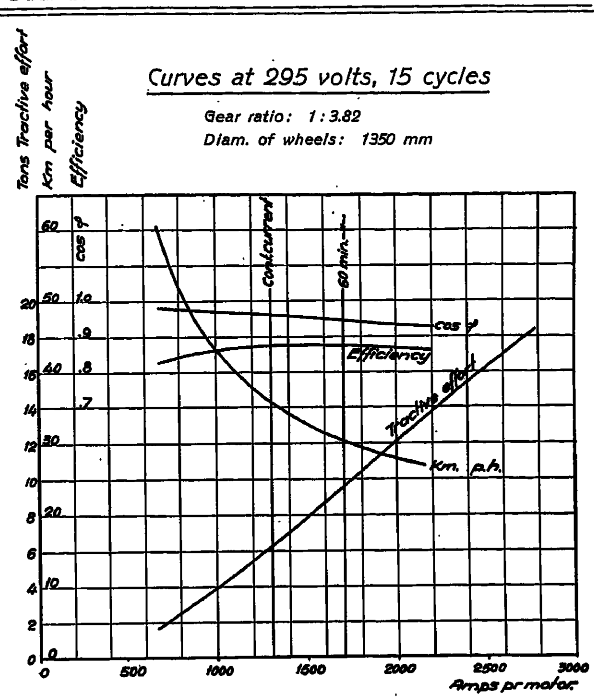


Fig. 4. Goods locomotive arrangement 0—8—0 with two motors type SJ 1303, 565 h.p., 455 r.p.m., 15 cycles.

component to meet both these voltages and its amplitude should accordingly lag behind the the armature current by about 45°. This is achieved most simply by connecting an ohmic resistance in parallel with the commutating winding, so that the current in this becomes shifted in phase relative to the main current.

The motors in question are constructed in accordance with this principle and due to this, and a careful selection of the various dimensions, they give sparkless commutation, even at relatively low speeds.

During starting the transformer voltage is wholly uncompensated, so that a slight amount of sparking is observed when the motors are fully loaded. The dimensions of the motors are such however, that this sparking is inconsiderable and not of such amount as to damage the commutator.

Experience on the Riksgrans Railway has shown that it is not necessary to regrind the commutators more often than once every year in ordinary service.

The normal pressure at the motor terminals is from 290 to 300 volts, at which voltage the motors give the outputs stated in the table. The general characteristics of the machines showing their performance at various loads are indicated in the curves, Figs. 3 and 4. The figure taken as the maximum tractive effort corresponds to about 26 or 27 % of the adhesive weight and these figures are about what is actually obtained under normal track conditions. The motors have on test in the shops and also in service shown that they are capable of an output corresponding to this tractive effort. The outputs given above are obtained with a temperature rise not exceeding 70° C in the windings and commutators and the 565 h.p. motor will give 450 h.p. continuously with the temperature rise not exceeding 60° C. Such a high continuous output as 85 % of the one hour rating with the same temperature rise is obtained by using the totally enclosed form and providing powerful ventilation. This has been obtained by a motor driven fan mounted directly on the motor and in the 0—4+4—0 locomotive each driving motor has its own fan, which at the same time provides cooling air for the transformer, while in the 0—8—0 and 4—4+4—4 locomotives each pair of motors is ventilated from the same double fan outfit.

Speed regulation is obtained practically free of losses as series resistance is not employed, the motors being connected by contactors to different terminals of the transformer through reactance coils, thus providing a voltage which varies by suitable steps up to the normal full value. The arrangement used is further described in the articles dealing with the equipment of the various locomotives.

A factor of particular importance is the effect which the motors themselves have upon the circuit in which they are connected, particularly with regard to the higher harmonics which are

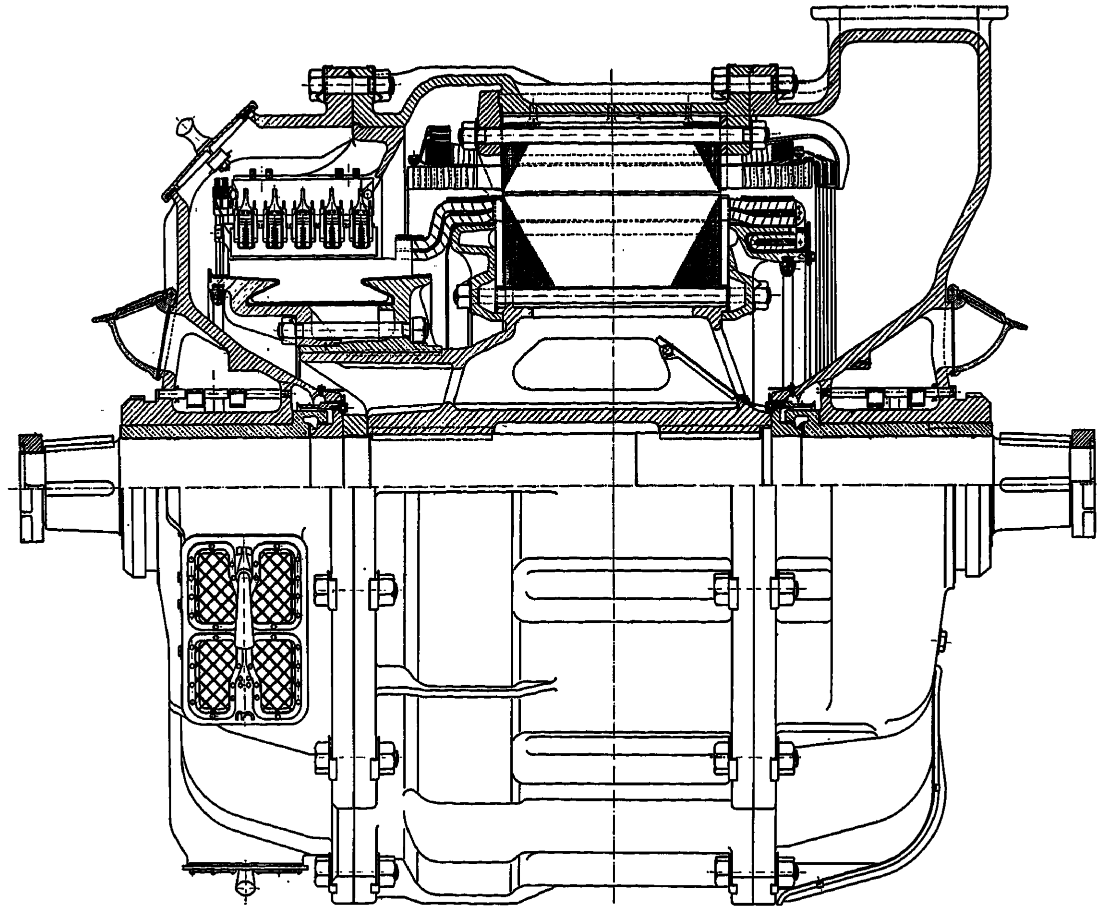


Fig. 5. Motors of type SJ 1103 side elevation and section.

superimposed on the voltage and current waves and which have a troublesome effect on the telegraph and telephone lines which run alongside the railway. In this respect the motors, and particularly the 470 h.p. motor, have shown themselves highly satisfactory and when a simple auxiliary apparatus is used they do not cause more disturbance than a corresponding continuous current motor would do.

Auxiliary Motors.

For driving the ventilating fans, pumps etc. a number of auxiliary motors are required for each locomotive and with the exception of certain compressor motors these run continuosly. They are series motors with compensating windings, some being provided with commutating poles in addition and are designed for the same temperature rise as is allowed for ordinary stationary machines. These motors are wound for 105 volts for the 0—4+4—0 locomotives and 125 volts for the others. For the former Asea supplied motors for the ventilators and vacuum brake pumps, forming part of the vacuum brake apparatus, and for the ventilating fans of the 0—8—0 and 4—4+4—4 locomotives.

Starting in general is effected by throwing the motor straight on to the full voltage. An exception is made in the motors for the 0—4+4—0 locomotives in which the motors driving the pumps for the vacuum brake are operated from the brake controller and starting is effected through resistances or reactance coils.

CONTROL GEAR FOR ELECTRIC LOCOMOTIVES.

In the present article the control gear for the single phase locomotives supplied to the Riksgrans (Swedish State) Railway and the Drammen Railway (Norway) is described in greater detail. In all these locomotives the apparatus generally is of similar pattern and the internal connections are to a great extent the same although the arrangement of the various parts is somewhat different.

The Swedish State Railway goods locomotives are provided with two motors each developing, on a one hour rating, approximately 400 kW or 540 h.p. and on continuous rating about 315 kW or 430 h.p. The current taken by the motors is approximately 1,700 amperes on the one hour rating and 1,300 amperes on the continuous rating and the motors are permanently connected in series. On the passenger locomotives four motors are fitted, each being of the power given above, and the equipment consists of a pair of complete two motor equipments.

Before proceeding to a description of the various pieces of apparatus employed we would direct the reader's attention to the diagram of connections given in fig. 1. The scheme of connections is practically the same for both goods and passenger locomotives, as one goods locomotive (or one half of a passenger locomotive) comprises a complete unit consisting of two motors connected in series, together with their accessories.

The number of driving steps provided on the controller is 11 for a goods locomotive (1 "stand-by" position and 10 running positions) and when two such locomotives are coupled together the number of steps is 20. The number of steps for a passenger locomotive is also 20.

This increased number of steps is obtained by arranging that when two motor units are coupled together the corresponding motor contacters are not closed together, but one from each locomotive or locomotive half in turn. This arrangement will be clear from the table given in fig. 2.

On the cover of the controller only those steps are marked as running positions in which the circuits are the same in both locomotives or locomotive halves.

The starting of a passenger locomotive is effected in the following manner:

The current collecting bow is raised against the trolley wire (this is effected in the first place by using the hand air pump provided, but on subsequent occasions, after the compresser has been running, compressed air is available for the purpose). The main oil switch is then closed and this connects the high tension winding of the transformer to the line, so that low tension current becomes available for the control circuits.

The operating circuits work at 120 volts (assumming a line voltage of 14,000) and are fed from terminal 16 on the main transformer.

The supply for the control circuits is taken through conductor 17 to the controller, through fuses and throw over switches, the object of which will be described later.

The reversing handle on the controller, which locks the main controller drum when in its "off" position is now turned to "forward" or "reverse", which causes the main reversing switch to be operated and closed in the corresponding position. This can only be done when the main contacts are carrying no current. At the same time a segment on the reversing controller makes contact, so that conductor 20 becomes alive and also the control leads 22 and 25, which supply the operating coils of the compressor and ventilator motors through switches and fuses, on the auxiliary control panel.

Moving the reversing controller sets free the push buttons mounted on the cover of the controller, which open and close the oil switch. These push buttons are mechanically locked in the neutral position of the reversing handle. By pressing down the right hand button the oil switch in the further locomotive or locomotive half is closed by means of an electromagnetically operated compressed air valve. The switch is opened again by pressing down the left hand button and current for this operation is supplied by a battery. The oil switch can in addition be opened and closed by hand direct; it can also be closed by operating the air valve by hand.

To start the locomotive the controller handle is first moved from the "off" position into the preliminary running position. By this movement the no-volt relay is first energised through the fingers and contacts 13—J on the controller drum. The supply of current to the no-volt relay coil is dependent upon the reversing switch being properly closed and none of the motor contacters can be operated unless this is the case.

The path taken by the current through the relay circuit is as follows:

Conductor 17, fingers F or B on the reversing controller drum, F or B and F^1 or B^1 on the control circuit interrupter, F^1 or B^1 and N on the main reversing switch, one contact of the overload relay N, the other contact of the overload relay 111, 111 and 112 the pneumatic

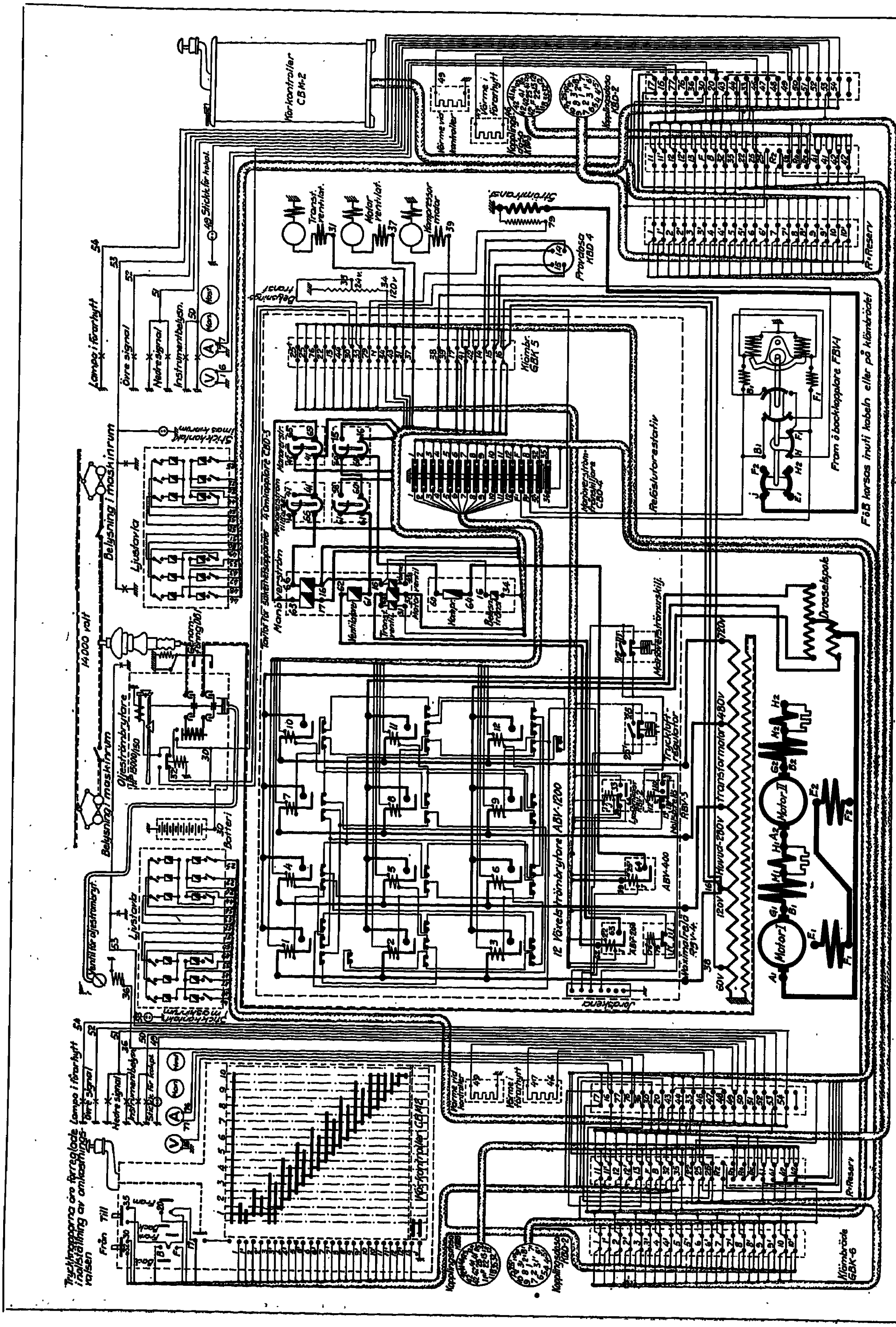
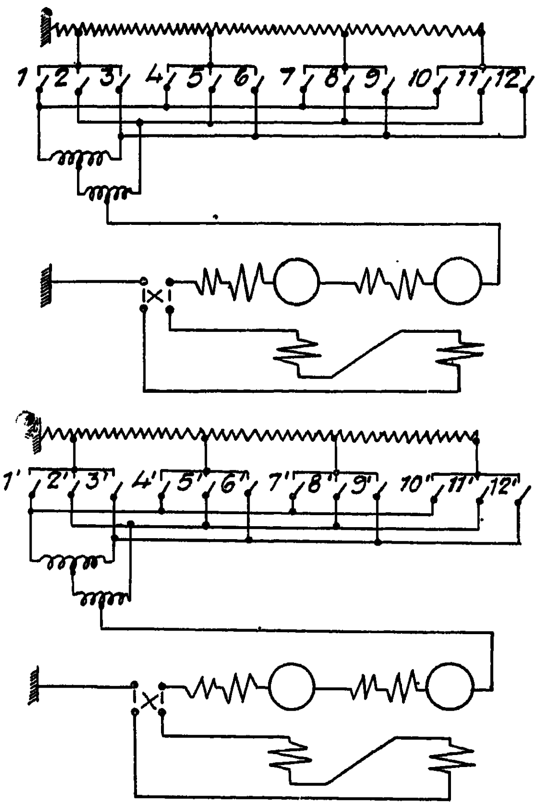


Fig. 1. Diagram of connections for the locomotives for the Riksgrans Railway.



Pos.	Switches																						
	1	2	3	4	5	6	7	8	9	10	11	12	1'	2'	3'	4'	5'	6'	7'	8'	9'	10'	11'	12'
½	●		●										●		●									
1	●	●	●										●	●	●									
1½	●	●	●											●	●	●								
2		●	●	●										●	●	●								
2½		●	●	●											●	●	●							
3			●	●	●										●	●	●							
3½			●	●	●											●	●	●						
4				●	●	●										●	●	●						
4½					●	●	●									●	●	●						
5					●	●	●										●	●	●					
5½						●	●	●									●	●	●					
6						●	●	●										●	●	●				
6½							●	●	●									●	●	●				
7							●	●	●										●	●	●			
7½							●	●	●											●	●	●		
8								●	●	●										●	●	●		
8½								●	●	●											●	●	●	
9									●	●	●										●	●	●	
9½									●	●	●											●	●	●
10										●	●	●										●	●	●

Fig. 2. Table of connections.

control circuit interrupter, no-volt relay 112 and thence through contacts 131—13 on the no-volt relay back to the controller and to the locomotive frame (13—J).

It will be seen that the no-volt relay energises itself after closing and at the same time connects the leads from the operating coils of the motor contactors to earth (the locomotive frame). The operation of the contactors takes place in order in accordance with the diagram fig. 1 and the table reproduced in fig. 2.

The motor contactors are fully interlocked, so that no incorrect connections can be made in the main current circuit.

The pneumatically operated control circuit interrupter opens when the air pressure is released by applying the brakes, effectively cutting off current to the motors and making its restoration impossible while the brakes remain on.

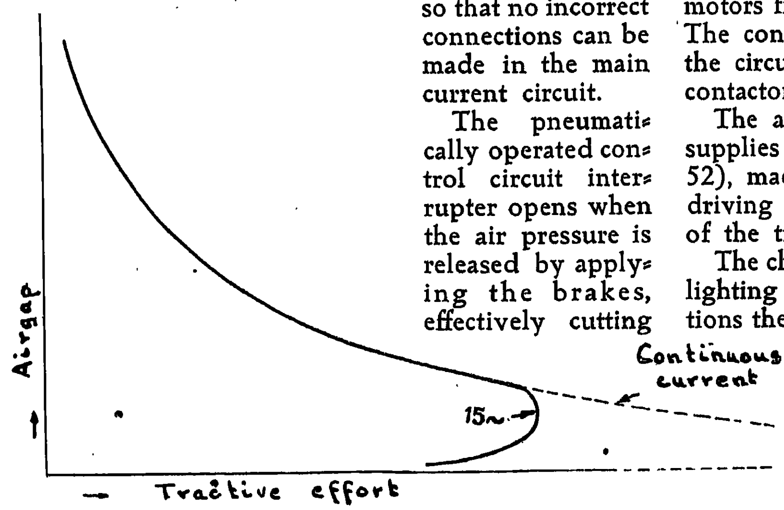


Fig. 3.

The upper contactor switch on the left of the switch frame serves to change over the control current supply from the transformer to the test coupling, while that on the right hand side supplies current for the control circuits to, or from, the other locomotive or locomotive half in the event of a breakdown of the transformer in one of the locomotives or locomotive halves. The left hand switch in the second row connects the ventilating motors either to 120 or 60 volt tappings. The lower voltage is provided for use in particularly cold weather. The right hand contactor switch in the second row changes over the leads to the compressor and ventilating motors from the transformer to the test coupling. The control circuit interrupter makes and breaks the circuits to the operating coils of the motor contactor, reversing switch, and oil switch.

The auxiliary battery already referred to also supplies current for the head light (conductor 52), machinery compartment lighting (53), and driving compartment lighting (54), in the event of the trolley wire being dead.

The change over is effected automatically by the lighting throw over switch. Under normal conditions the lighting circuits are connected to a small lighting transformer wound for 24 volts supply.

The lighting switchboards in each driving compartment, in addition to switches and fuses for the lighting

circuits, are provided with similar apparatus for the heating circuits, and the coils of the compressor and ventilator relay switches as before stated.

Construction of the apparatus.

In all apparatus for use in railway work suitability of design is an extremely important point. The smallest mishap may upset the working of the whole system. The greatest care in the construction and erection is therefore a primary consideration.

The motor contactors which continually have to make and break the heavy current to the motors are the most important pieces of apparatus in the whole equipment. These as well as the other relay switches must be designed with consideration to the great voltage variations which occur in practice (25 % to 30 %), a problem which involves many constructional difficulties.

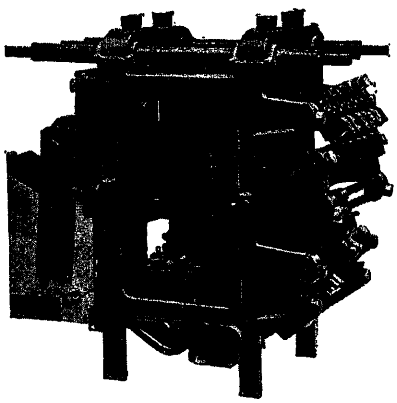


Fig. 4. Relay contactor.

This requirement in conjunction with the provision of a suitably heavy contact arm to deal with the working current, and a high pressure between the contacts, determines the construction of the contactors. Designs in which the weight of the contact arrangement and the contact pressure are thrown direct on the armature of the operating magnet are unsuitable.

The reason for this is to be found partly in the weight of the armature and partly in the

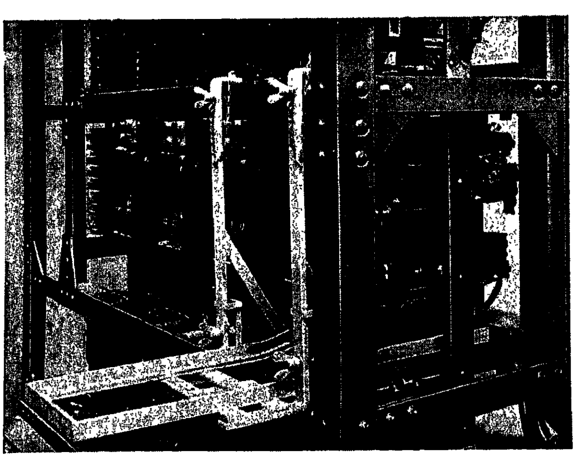


Fig. 5. Special sledge for removing the contacters from the frame.

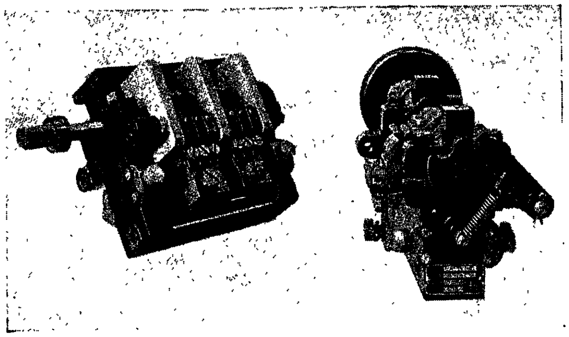


Fig. 6. Contactor switch.

shape of the tractive curve for an AC electromagnet with damping winding. An example of such a curve is given in fig. 3. The appearance of this shows that during the last part of the movement when the extremities of the poles approach each other the power falls off considerably, due to the effect of the damping winding. This occurs just when the magnet, having regard to the contact pressure, should be giving its maximum pull. The dotted line shows the tractive effort with DC. From an inspection of these diagrams it is obvious that

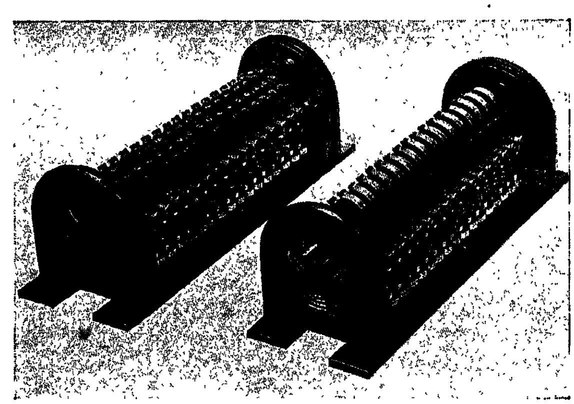


Fig. 7. Interrupters for the operating current.

the construction to be aimed at is one in which the magnet, in the position it is in when the switch is closed, can be loaded to the greatest extent. This is obtained by using a specially jointed lever between the operating magnet and the contact arm, a principle which has also been used in the construction of Asea's newest type of relay contactor shown in fig. 4. Special sparking contacts are not provided, the current being broken at the main contacts. By providing a rolling action of the contacts mounted on the contact arm it is assured that both these and the fixed contacts shall be kept smooth and in good current carrying condition. All the magnetic pull available has been fully utilised.

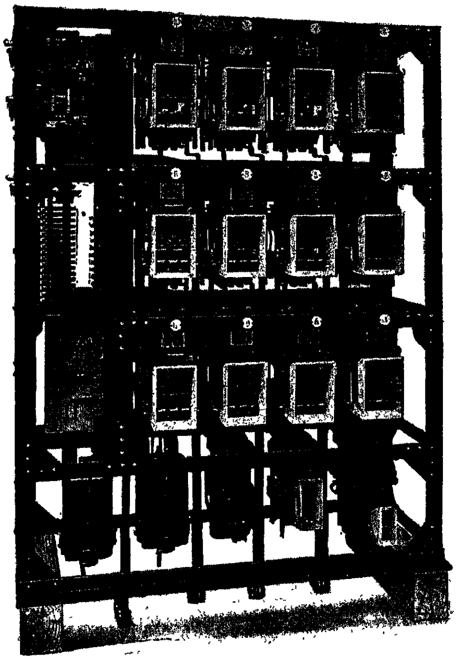


Fig. 8. Relay frame, front view.

Fig. 9. Relay frame, back view.

The auxiliary contactors close with a motion which causes the surfaces to rub together, ensuring good contact. The construction also allows two rows of fingers to be used (in addition to a large number of auxiliary contacts), the arrangement being the simplest possible. The auxiliary contacts and the holders for the fingers are mounted upon micarta insulated iron bolts. The arcing shield is loosely supported and held in place by springs, so that no special tool is required for removing it.

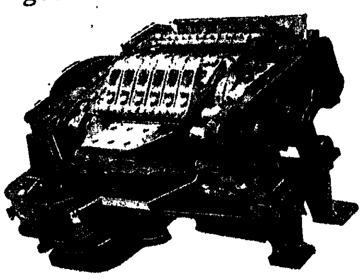


Fig. 10. Reversing contactor.

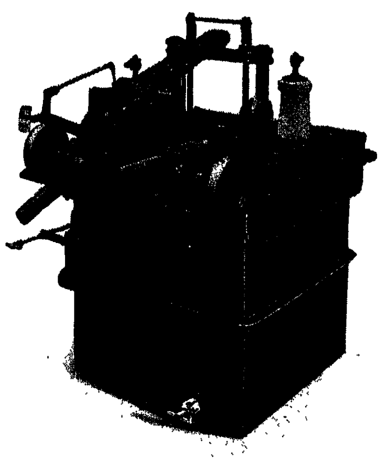


Fig. 11. Oil switch.

The relay contactor is so designed that it can equally well be hung in the relay frame or supported from below. The method of hanging has been adopted however, as possessing greater advantages from the point of view of freedom from damage in the relay frame. In order to make it possible for one man, without difficulty, to remove one of these contactors from the frame, a special sledge has been designed for dismantling, the general appearance of which is shown by fig. 5. In most cases it is not necessary to remove the contactor any further than on to this sledge, as when it is so withdrawn it is easily accessible and minor repairs can be easily effected.

The smaller relay switches for the compressor and ventilator motors are designed generally in a similar manner to the main motor contactors.

The construction of the contactor switches and interrupter for the operating current will be clear from figs. 6 and 7. Micarta insulated bolts have also been

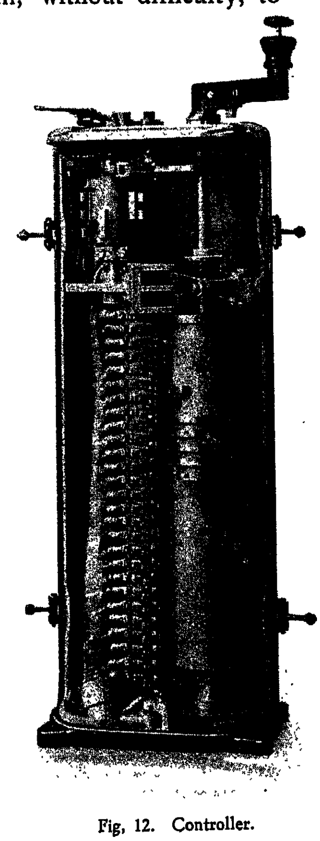


Fig. 12. Controller.

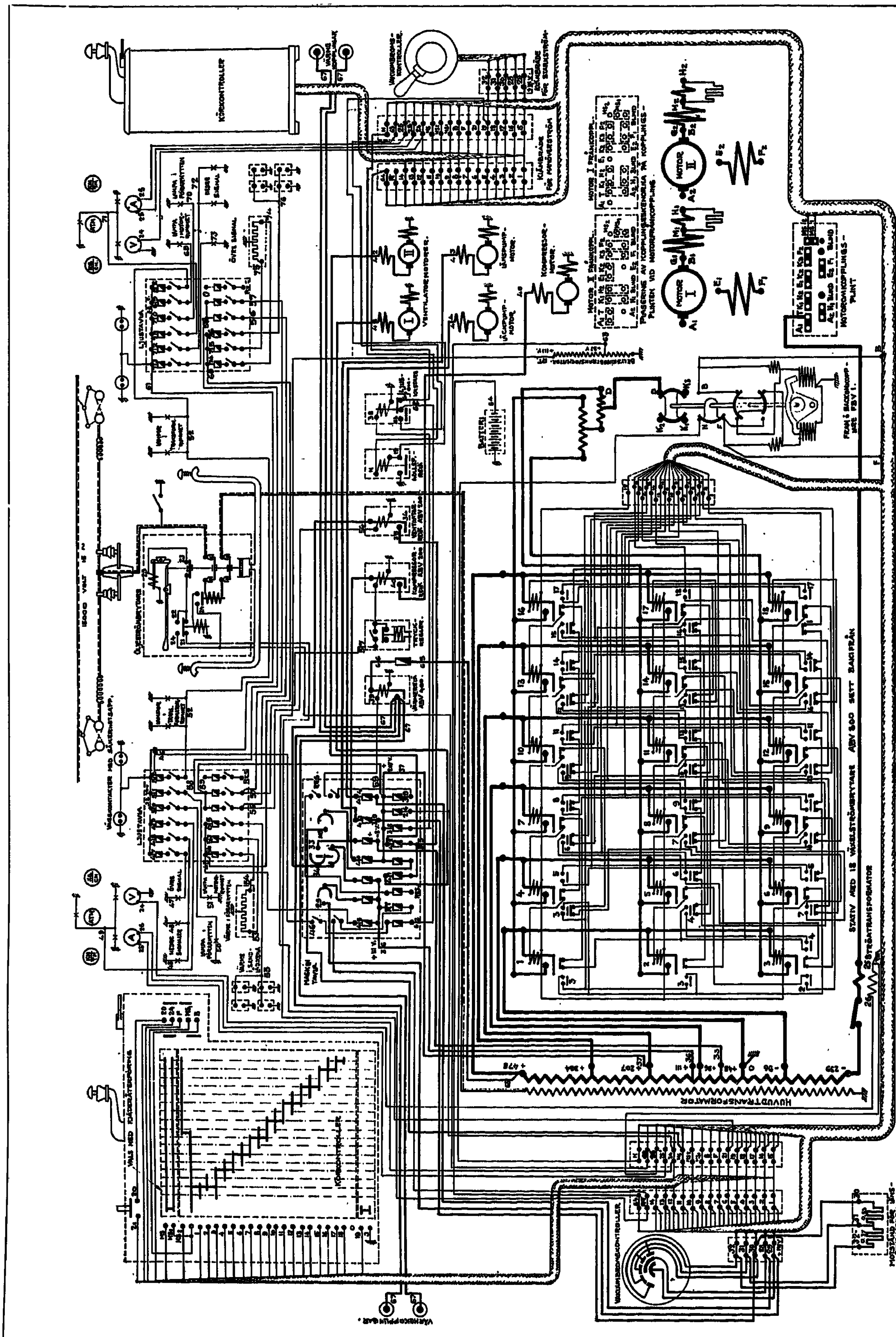


Fig. 13. Diagram of connections for the Drammen Railway's locomotives.

used to carry the contacts and fingers for these. The fingers are of similar pattern to those used for the auxiliary contacts on the motor contactors.

All the apparatus so far referred to is mounted in a single relay frame of which fig. 8 shows the front and fig. 9 the back. In this frame are also mounted the air pressure regulator, the pneumatic control circuit interrupter, and two panels with fuses and terminal connections. The hand operated contactor switches are worked when required by means of the crank handle taken from the reversing controller.

The reversing contactor, fig. 10, has been designed as an electromagnetically operated drum contactor, the segment and fingers in this case also being supported on micarta insulated bolts. The operating magnets or relays are of the same pattern as are used for the motor contactors. The whole of the magnet system with the toothed segment is removable.

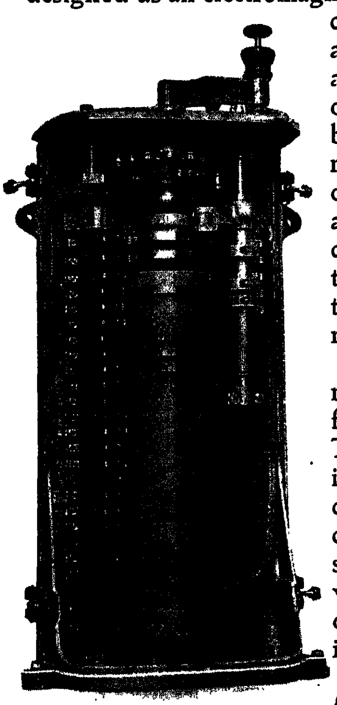


Fig. 14. Controller.

Fig. 11 shows the main oil switch and fig. 12 the controller. The current collectors, isolating switches and coupling boxes for the control leads are well shown in the exterior view of the locomotive on page 38 of the June issue of the Asea Journal.

In the locomotives for the Drammen Railway the motor output is somewhat less, namely 350 kW or 475 h.p. (one hour) and about 290 kW or 390 h.p. continuous. In these locomotives also the two motors are permanently connected in series.

The connection diagram for these locomotives is shown in fig. 13 and although, as previously stated, the connections are generally similar to those in the Swedish State Locomotives, there are at the same time a number of differences worthy of note. These locomotives are not so designed that two can be operated from one controller. On this account the outside couplings for the control circuits, and the control circuit interrupters, are omitted. The number of running steps is in this case 17 and the number of motor contactors 18. The correct operation of these is here also insured by thorough interlocking. An arrangement has been used to make it possible to uncouple one motor if a breakdown should occur. This disconnection can be made by removing a simple connecting link. This consists of a copper bar which is connected as necessary, so that either both motors are in circuit or only one of them. The location of the necessary links is clear from the diagram. By breaking the connection MS_1-MS_2 the supply of operating current to the motor contactors is broken if the driver tries to turn the controller beyond running position 8 when working with only one motor. In this way the motor cannot be subjected to too high a voltage.

On the main transformer a suitable terminal

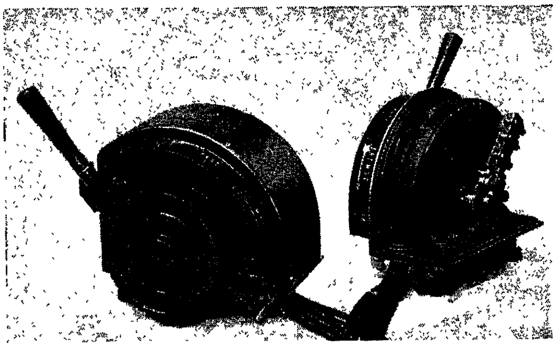


Fig. 15. Vacuum brake controllers.

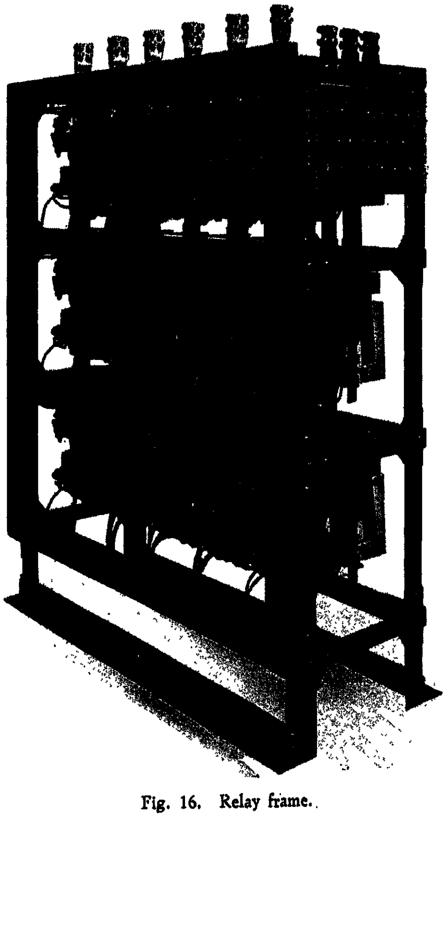


Fig. 16. Relay frame.

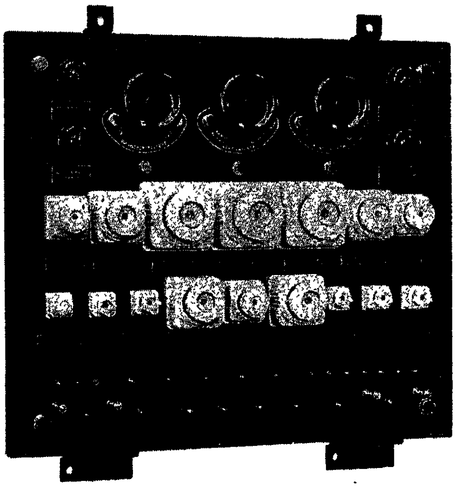


Fig. 17. Auxiliary panel, front side.

in the middle has been earthed so as to reduce the voltage to earth at the motors.

In addition to the motor controller, fig. 14, there is a vacuum brake controller, fig. 15, in each driving compartment. This last takes the place of the usual brake valve in a compressed air brake system, but controls at the same time, through electric contacts, the main and auxiliary vacuum pump motors in such a way that in the position "run" only the small auxiliary pump is connected and in the position "release" the auxiliary and vacuum pumps operate together. When braking begins, and in the brake controller's "neutral" position both motors are disconnected. The handle of this controller can be removed when in the "neutral" position. The brake controller is locked in this position when the handle is taken away. For both brake controllers on each locomotive only one handle is provided and similarly there is only one handle each for the reverser and controller. Braking and driving can accordingly only be carried out from one position at a time.

Although the vacuum brake system is used a small compresser is also provided on the locomotive with compressor relay switch and compressed air regulator for certain auxiliary devices, such as the sanding apparatus, the whistle, raising the pantographs and closing the main oil switch. Contrary to the arrangement in the Swedish State Railway locomotives the closing of the main oil switch is effected direct by depressing the air valve. The opening of the switch is however effected in the same way as in the Swedish State locomotives.

Besides current for the motors the transformer also supplies current for warming the train, which is conducted to the coaches through couplings at each end of the locomotive. The heating current may be up to about 250 amps

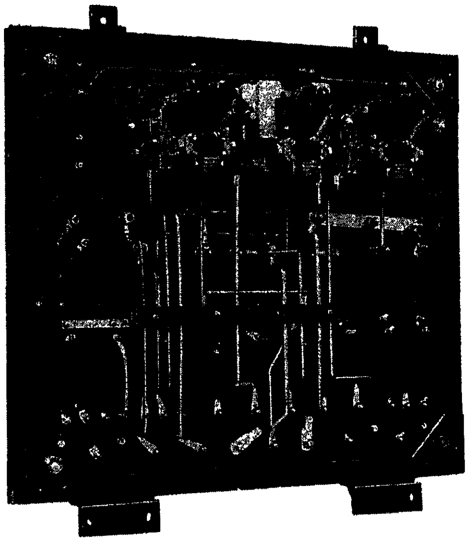


Fig. 18. Auxiliary panel, back side.

at a voltage of approximately 500. The control circuit voltage is about 200 with 15,000 volts on the trolley wire.

Fig. 16 shows the relay frame. The construction of the contactors corresponds to those on the Swedish State Railway equipments and the removal of a contactor is effected in the same way (Fig. 5).

The auxiliary panel is shown in fig. 17, fig. 18 being a back view. The relay switches are of the same type as for the Swedish State Railway locomotive.

The high tension leading through insulator and disconnecting link are combined in the Drammen locomotive into a single apparatus.

A general view of the locomotive is shown on the front page of this issue. The mounting of the current collectors and the high tension leads, as also the heating circuit couplings are clearly visible in this potograph.

Vesteras, 1924, Vestmanlands Allehanda Printing Co.

ASEA-JOURNAL

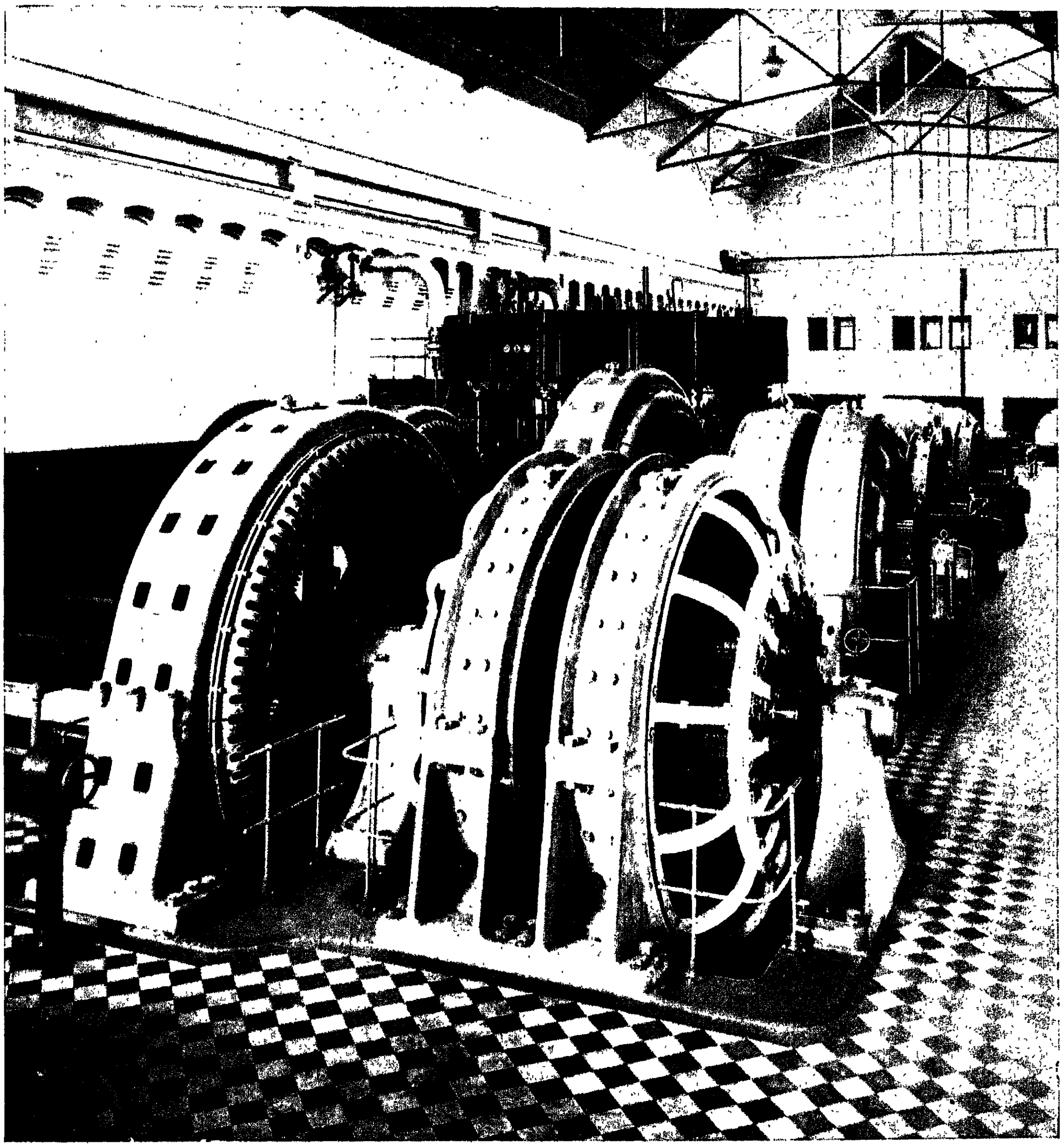
ALLMANNA SVENSKA
ELEKTRISKA A.B.
VESTERAS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

AUGUST

All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesteras, Sweden.
Permission is given to reprint articles or extracts from this journal, on condition that the name — Asea-Journal — is clearly stated.

1924



Interior of power station at Gothenburg, Sweden, equipped with Asea motor generators.

ASEA'S CONTINUOUS CURRENT MACHINES.

When the company commenced work in the year 1883 the first machines built by Asea were DC machines. The construction of these was based upon the inventions patented by Jonas Wenstrom, who was at that time the Chief Engineer to the company. The most important and epoch making of the innovations introduced by him consisted in placing the armature windings in slots in the sheet iron stampings, of which the armature was built up, a principle which has since been used to an enormous extent in all kinds of electrical machinery. As regards their magnetic features these machines were "modern", having low pole cores and short magnetic flux paths. These early machines were characterised besides by their strength and solidity in mechanical respects, which was very marked by comparison both with foreign machines and with those turned out by Swedish competitors.

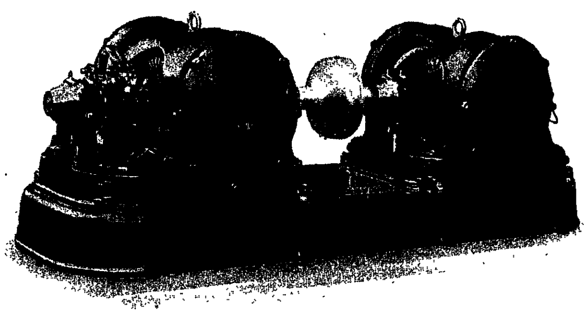


Fig. 1. DC machines of Wenstrom type.

The general appearance of these types, which were built between 1883 and 1886 in 9 sizes ranging from 0.9 to 23 kW can be gathered from the working drawing reproduced in fig. 2. Many of these machines are still in use.

Based on the experience gained with the foregoing, Wenstrom in 1889 constructed a second series of DC machines in 9 sizes between 1.65 and 44 kW. These were 4 pole machines. They possessed great overload capacity and were noteworthy for their particularly sound mechanical construction and their characteristic and striking appearance. They were built in very large numbers and became generally known as the "Wenstrom Well Known Type", fig. 1.

From 1880 these machines were supplied in great numbers for electric lighting plants in towns, factories, etc. only. From 1890 onwards, plants for the transmission and distribution of

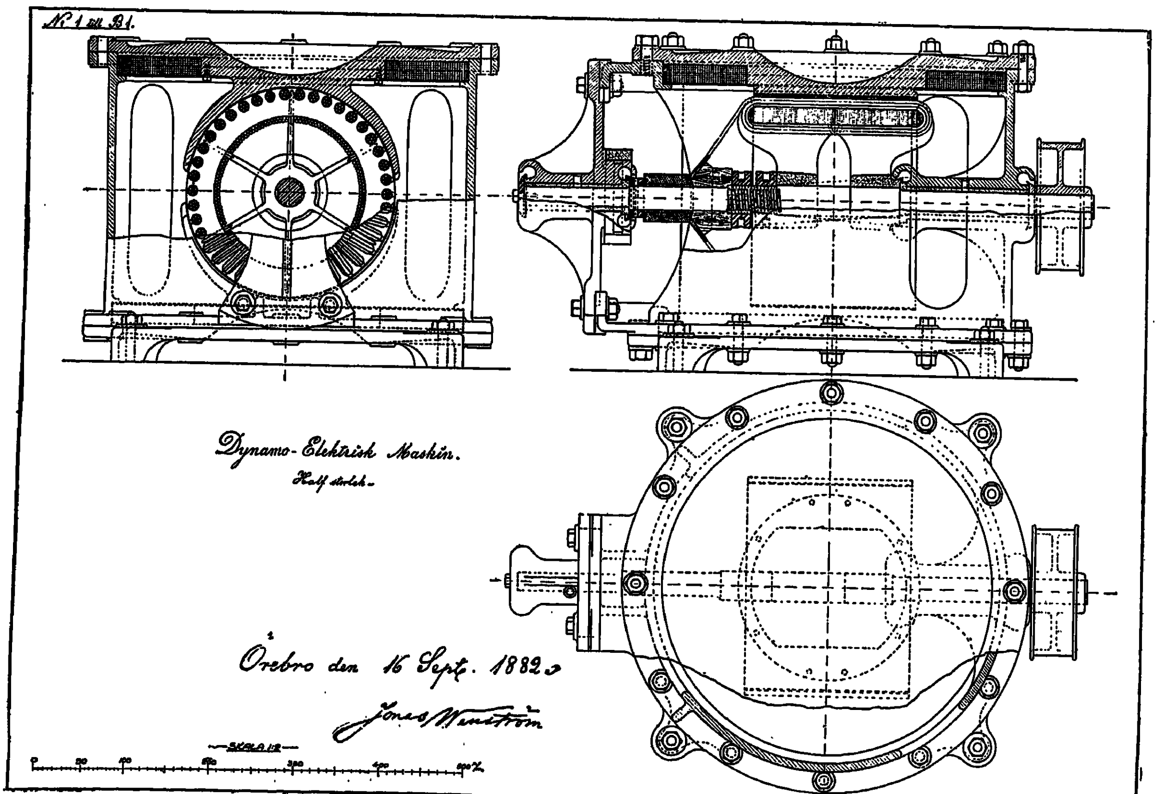


Fig. 2. Facsimile of a working drawing for dynamo type B No. 1.

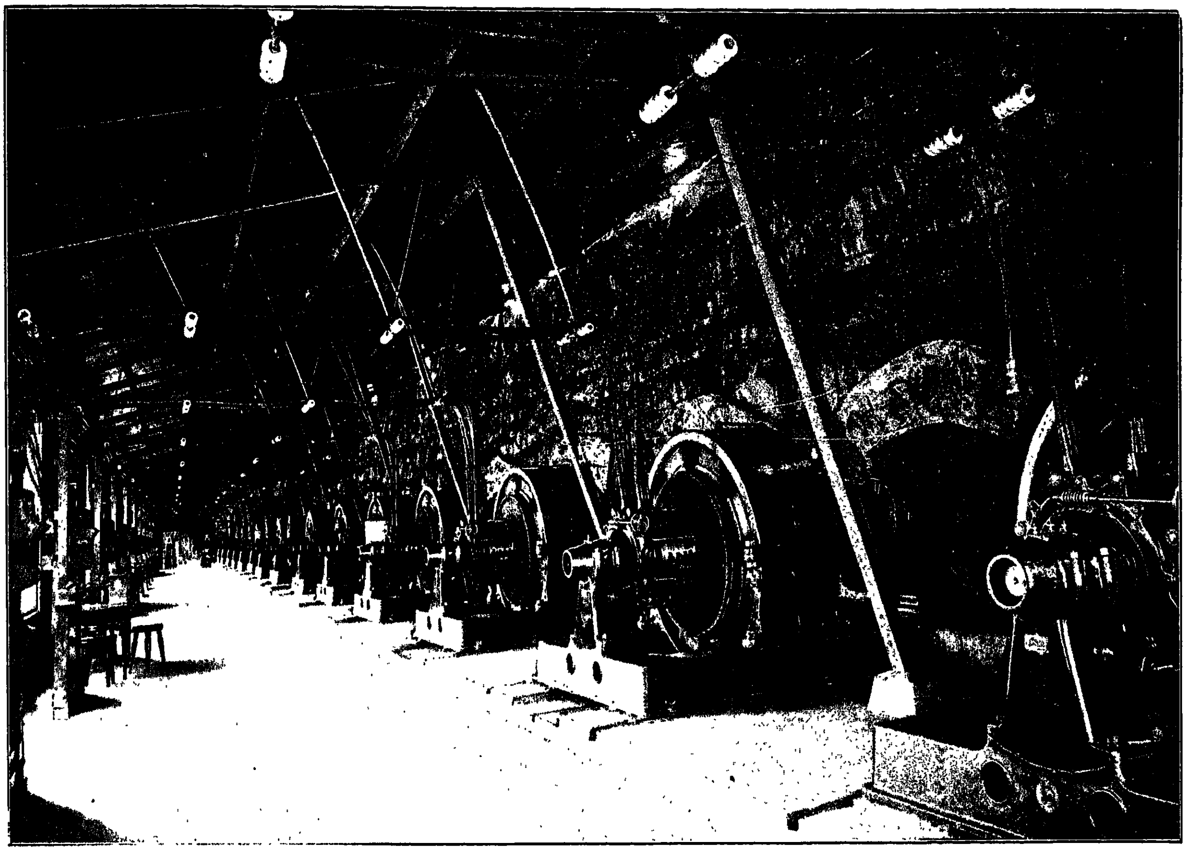


Fig. 3. Interior of the Stockholm Super-Phosphate Co. power station at Mansbo, Sweden, built in 1893—96.

power were equipped and the Wenstrom type found a further field of application. Several installations of this kind in connection with workshops, saw mills, paper mills etc. were laid down in Sweden, and a power transmission scheme from a 60 h.p. water turbine to a paper mill 3 km away at 1,300 volts DC may be specially mentioned. At the beginning of the '90s also, the first electric locomotive ever built in Sweden was supplied for use on a light railway at a wood pulp mill.

As will be seen from the illustrations, Wenstrom from the very first adopted the principle of construction with radial poles placed inside a circular yoke, which afterwards became standard all over the world for DC machines.

A number of different types of machines outside the standard series of Wenstrom dynamos were made, after the company had moved to the new workshops in Vesteras in 1892. This was necessary, partly because plants were put down for which the largest types in the standard series were inadequate, and partly as great efforts were made soon after 1890 to produce machines in larger sizes to correspond to the requirements of the time. The period was not a good one for the DC system, chiefly because the three phase system had just come to the front and in all quarters was absorbing the chief part of the interest. All effort and thought was transferred to the development of three phase machines and DC machines were put to some extent into the shade.

For electrolytic work however, the three phase system could not be used and this field was left open for the DC machine. The largest DC machines which Asea supplied during the '90s were made for this special work and may well be shortly referred to.

The chief plants of this kind were at Stockholm Super-phosphate Works at Mansbo, Dalelven, which was equipped in 1893 with 8 DC generators, each for 1,200 amps at 115 volts and 265 r.p.m., and in 1896 with a further 5 generators, each of 1,400 amps and 160 volts at 235 r.p.m. (fig. 3) and the Finish Electro-Chemical Co. at Imatra to which in 1898 5 generators were supplied, each for 2,000 amps at 110 volts and 133 r.p.m. (fig. 4).

The generators for the above installations and a number of lesser sizes were furnished with the armature winding patented by Sayers in 1891,

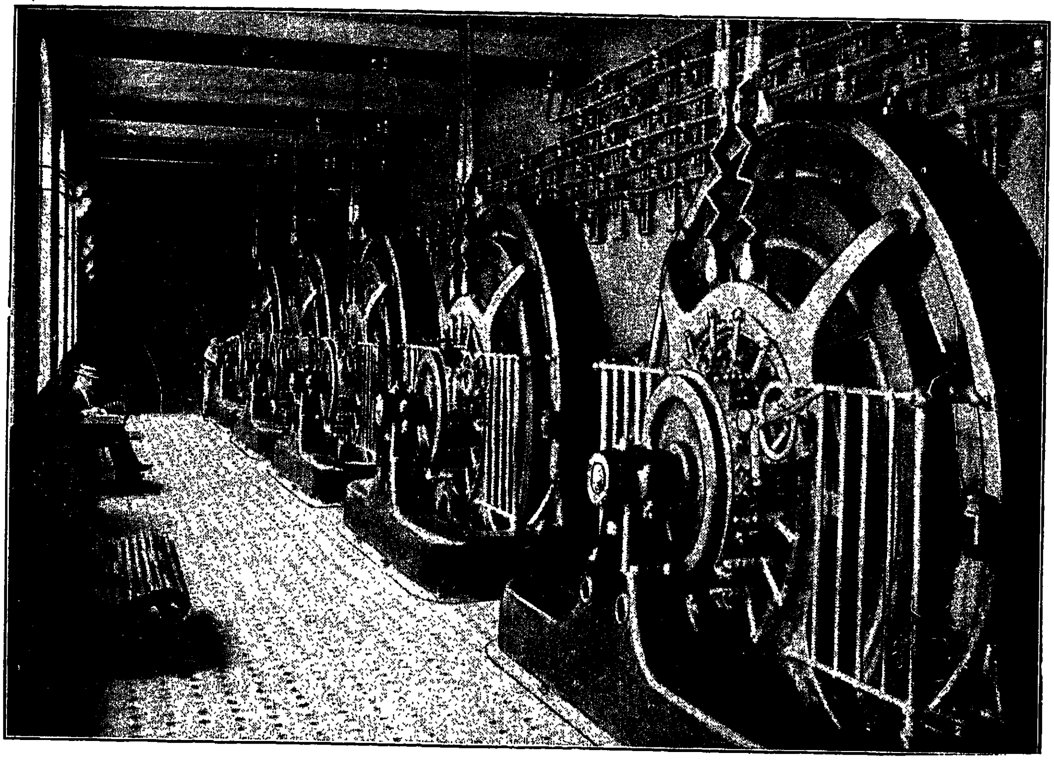


Fig. 4. Interior of the Finish Electro Chemical Co. power station at Imatra built in 1898.

with special commutating coils laid in the arma-ture-slots, Asea having obtained the right to make use of this patent in Sweden. According to modern ideas the arrangement employed was not quite satisfactory, but at that time it was one of the best means known for overcoming the difficulties experienced in commutation in these large machines, which were moreover furnished with copper brushes, on account of the heavy current.

Another means of improving commutation was the compensating winding, which consisted of a winding carrying the main load current of the machine and placed in slots in the pole shoes. This principle was patented in 1884 by Menges and was experimented with by Ryan and Deri among others in 1893 and 1900 respectively, but did not come into its own until it was used at a later date in conjunction with commutating poles. During the '90s Asea built several machines with such windings; the first occasion being when the Stora Kopparbergs Bergslags Co. in 1896 placed an order for 8 motors, each of 30 h.p. at 300 volts and 550 r.p.m. for driving hoists for lifting charcoal to the

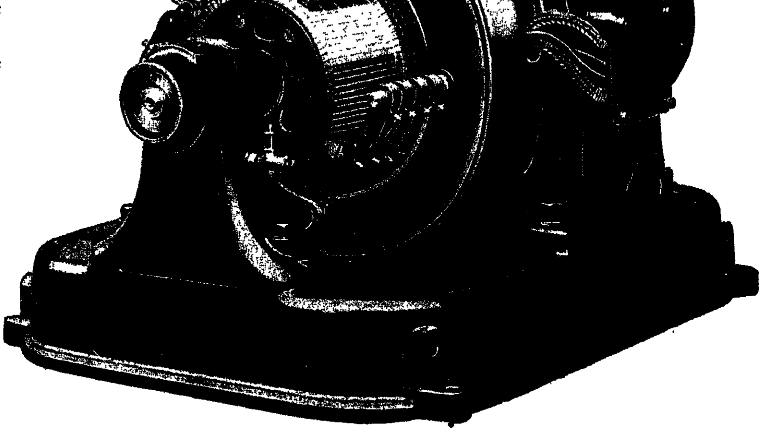


Fig. 5. Continuous current motor type DMB, 1901.

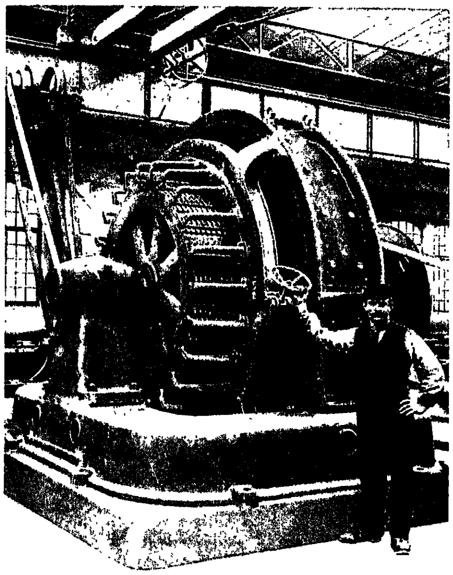


Fig. 6. 750 kW DC generator for Alby Chlorate Works, 1899.

furnaces at Domnarvet. This contract embodied the following requirements: "Only the slightest amount of sparking is to occur with the brushes in the neutral position, even should the current increase to 50 % above the normal. The brush gear and other details shall be so arranged that the direction of rotation can be changed quickly and without inconvenience. The machines to operate equally well in either direction and to be equipped with carbon brushes". To meet these requirements motors were built of the 4 pole type with laminated fields and with the salient poles provided with compensating winding, and with the shunt winding spread over the pole in the same slots as the compensating winding. (This last arrangement is embodied in Deri's patent of 1900.) One of these interesting motors is now in Asea's museum. The generators for this plant (330 volts, 400 amps, 300 r.p.m.) were also furnished with compensating windings. Another similar generator was delivered in 1898 to Tammerfors for 1,400 amps at 120 volts and 300 r.p.m. Of other machines which were constructed in the late '90s may be mentioned the "C" type, arranged for direct coupling to steam engines in central stations for lighting purposes and running at relatively low speeds. At this time also the smallest types were developed down to 0.2 h.p.

Although during this time Asea's designers put in the greater part of their work and interest on the development of the three phase machines they also spared time for the DC machines and their commutation problems. The result was not apparent by the production of any new series of machines (similar to the Wenstrom series) but was shown in the construction of the generators which were furnished for electrolytic purposes, which marked a considerable step forward in development. It must also be remembered that the arrangements made

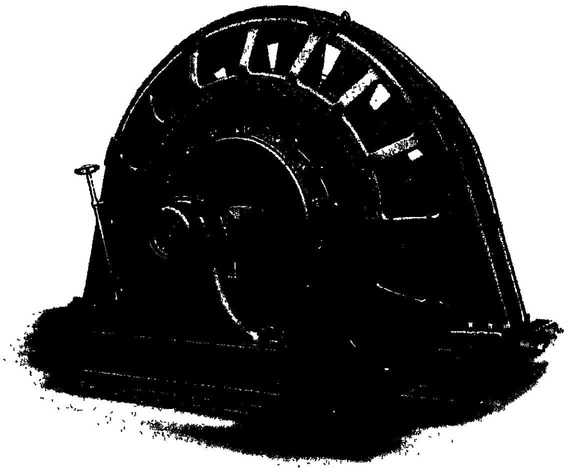


Fig. 7. DC generator, 1904.

in these machines for improving the commutation must be looked upon as research work. The proportion of the large machines was carefully considered and constituted a considerable advance in itself, as is demonstrated by the fact that the machines both at Mansbo and Imatra among others are still in every day use as also are some of the hoist motors at Domnarvet.

The large Wenstrom types were improved at the close of the '90s by being provided with

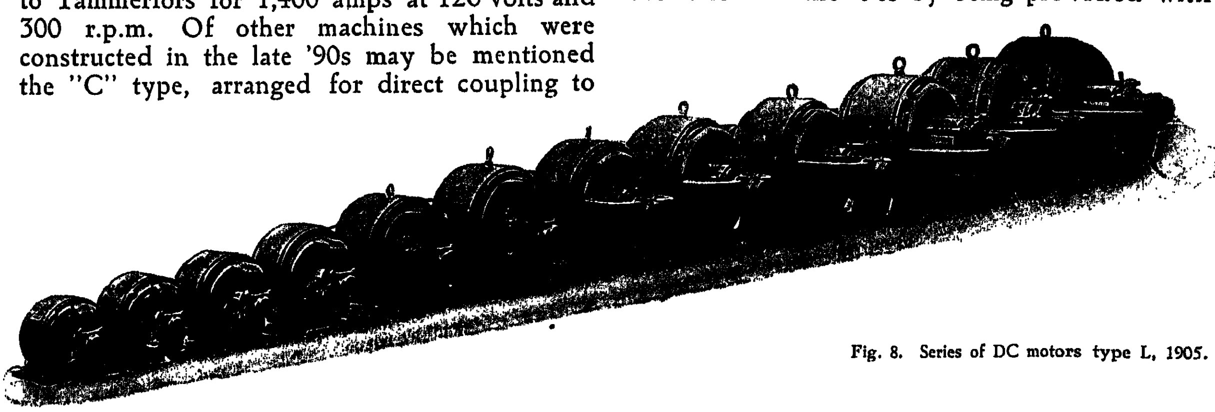


Fig. 8. Series of DC motors type L, 1905.

circular yokes of cast steel with radial poles all provided with field coils. Meanwhile as further improvements were shown to be necessary, a new series DMB-DLB was brought out in 1900—1902 in sizes from 10 to 300 kW. The outstanding features of this series were that the armature coils were former wound and laid in rectangular slots. The commutators were of larger diameter and provided with more segments than had been previously used, while carbon brushes were employed exclusively.

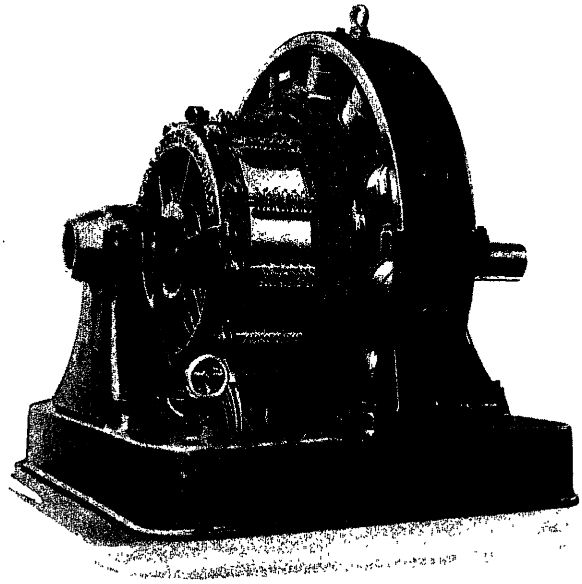


Fig. 9. DC generator type LD, 1906.

The yoke, of cast steel, was circular and rested, together with the pedestal bearings, on a box bedplate (fig. 5). The poles were built up of laminations and secured to the yoke by screws. The brusholders were of a new pattern and were supported on brush spindles from a rocker ring fixed to the yoke. The air gap was relatively large, the ratio between the armature and field ampere turns well considered, so that as a result the machines behaved exceedingly well with regard to commutation, and at different loads only a very small amount of brush shifting was required.

The most noteworthy large machines produced between the years 1899 and 1901 were three generators for Alby Chlorate Works, which were wound for 220 volts, 3,400 amps at 200 r.p.m. and provided with gauze brushes, fig. 6. These machines are still in use and during their many years service have worn out one or two sets of commutator segments. Two further generators supplied at this time were installed by the Stockholm Southern Tramways

Fig. 10. Interior of the Thule station of the Stockholm electricity works for which Asea in 1907 delivered five 1,000 kW motor generators.

Co., which were each for 165 kW at 575 volts and 150 r.p.m. with carbon brushes and small armature reaction, giving accordingly particularly good commutation.

It was after the critical industrial years 1901—1903, that the demand for DC machines first assumed such proportions that mass production could be considered for the smaller sizes. The reasons for the greater utilisation of the DC system, which was found by degrees to be comparable in its own domain with the AC system, are to be found in the increased demand and in the decided improvements which were made in the years immediately preceding. Power stations, especially in the large towns increased in size, following the introduction of satisfactory metallic filament lamps, also electric tramways were constructed; and as small industries developed to an ever increasing extent they found it more economical to purchase electric motive power from the central stations than to produce it in isolated plants. For these central station plants DC was found to be very suitable, chiefly on account of the certain, and immediately available, reserve which could be obtained by the installation of a storage battery. The DC system further found a most natural use in plants where continuous speed regulation was required, as in colliery winders, rolling mills, certain paper making machinery, etc. Of the striking improve-

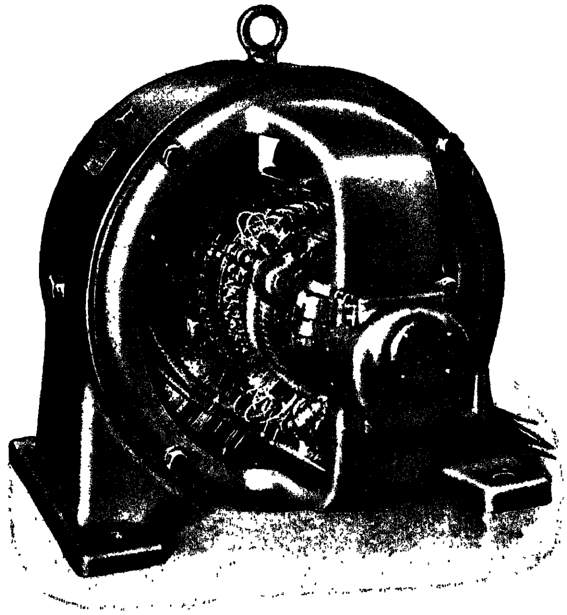


Fig. 11. DC machine type K.

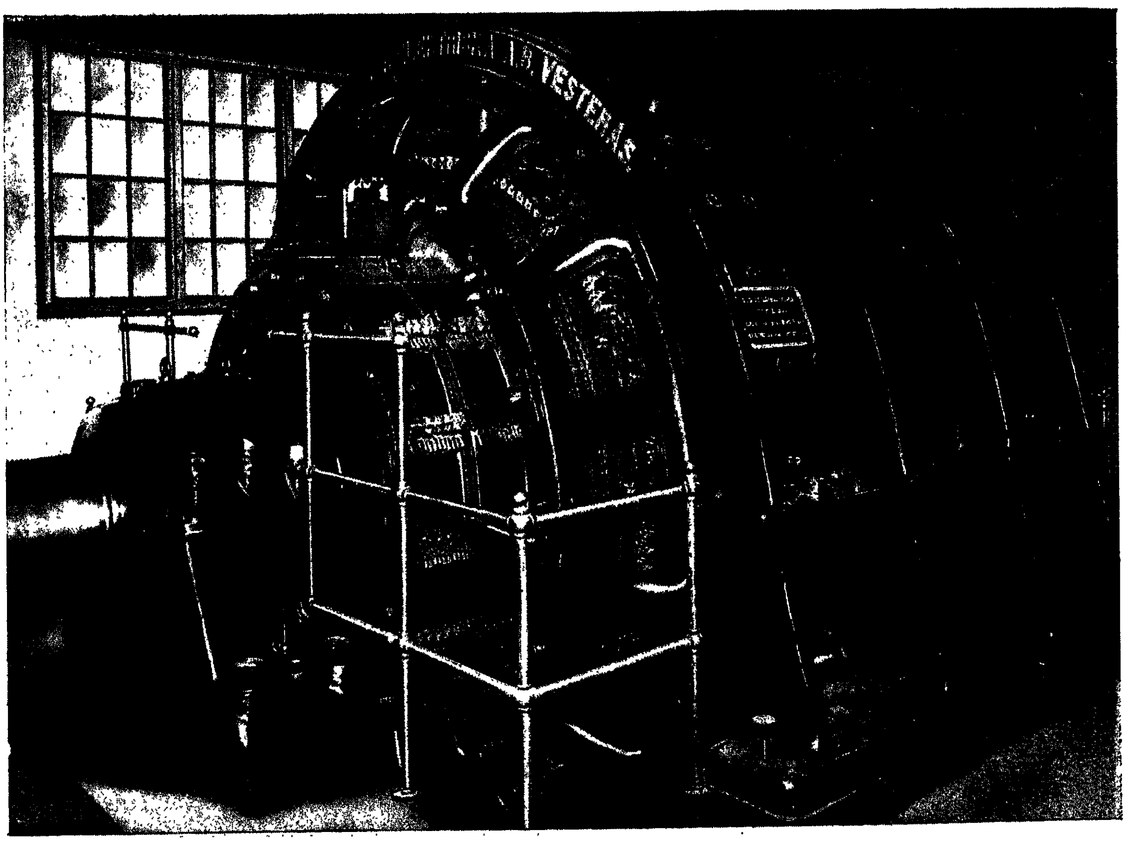


Fig. 12. DC motor maximum output 7,000 kW at Domnarvet Iron Works, Sweden.

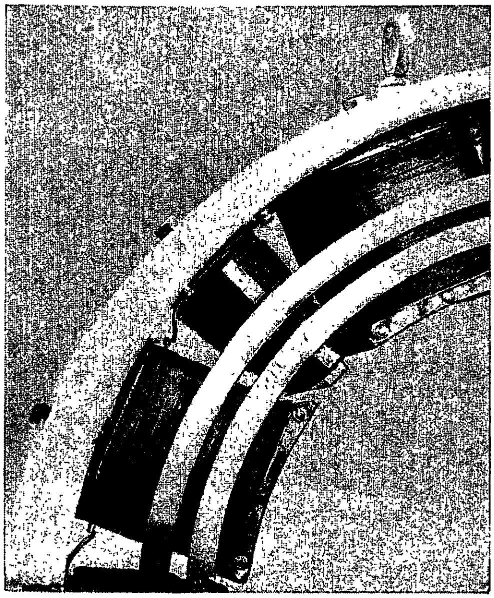


Fig. 13. Section of yoke with interpoles.

ments obtained by the use of interpoles more will be said further on.

In 1904 and the years immediately following Asea built many large machines for electric power stations in Gothenburg, Stockholm, Malmo, Uppsala, Jonkoping etc. as well as for various factories, fig. 7. Commutation continued to occasion considerable difficulty and thought, but as high speeds were not in demand designers were content to devote themselves to suitably dimensioning the pole shoes, providing a large air gap and using carbon brushes, points which in general ensured good operation, as brush shifting with varying loads was in general permitted. At this time also, methods of calculation and design were much improved, particularly in the direction of commutation.

The whole series of DC machines was at this time newly constructed and made more homogeneous, the different details being standardised to conform to the organisation of the shops on modern lines to meet the needs of mass production. This series of "L" types were made in 12 sizes from L 2, 0.5 kW to L 300, 60 kW and were constructed with circular yokes of cast steel, provided with supporting feet, large circular wrought iron poles, with laminated pole shoes, end bearing brackets and brush rockers carrying brush spindles fixed on the inside of the bearing, which construction was found to be cheapest and most suitable for production in quantities, fig. 8. The brushholders were of a new design, carbon brushes being used and made a sliding fit in the holders. Of these types large numbers were made during the years 1904—1912 and entirely displaced the earlier types of corresponding sizes.

The series was later extended by the addition of 5 sizes LD 400 to LD 800, arranged for direct coupling to steam engines, Diesel engines, and similar prime movers, running at a relatively low speed. These last machines were multipole and provided with pedestal bearings and bedplates, fig. 9.

The provision of interpoles for all sizes of DC machines constituted an epoch in development. The commutation problem was thereby for the time being definitely solved and good commutation was secured, which was quite independant of the strength and distribution of the main field, which made the use of DC machines possible under the most varying conditions of overload, and voltage and speed regulation.

As long ago as the close of the '80s Jonas Wenstrom had conducted research work with interpoles, (*i. e.* poles placed between the main poles and provided with windings through which the load current of the machine was circulated), on one of his machines. When the machine with this arrangement was tested it was reported that it did not run better than it had done before the interpoles were fitted and the matter

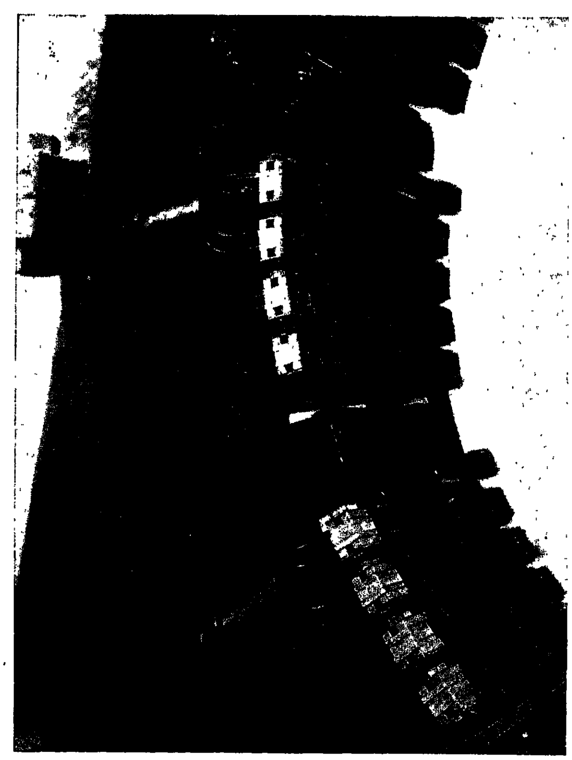


Fig. 14. Section of yoke with interpoles and compensating windings.

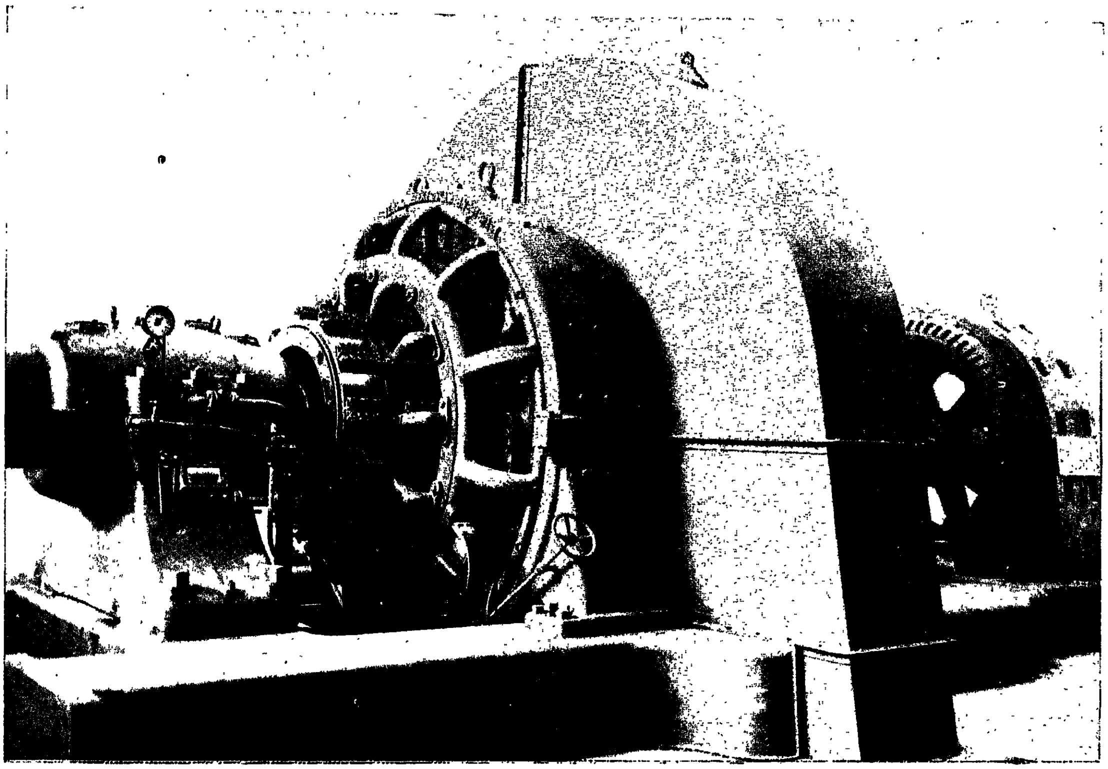


Fig. 15. Ilgner set at Domnarvet Iron Works, Sweden.

was allowed to drop without any further investigation, which is easily explained when one bears in mind that at that time the tests carried out on finished machines were not of a very searching character and also that the designing offices and shops were situated in different towns, so that they could not co-operate together particularly well in work of this kind.

Further research on interpoles was done in 1900 on a special type of motor provided with speed regulation for driving machine tools and the results were in this case judged to be very good, but as the manufacture of this particular type of motor was soon afterwards discontinued the idea of commutating poles was placed on one side, if not altogether forgotten.

The advent of the new century was marked by a great deal of work by technical men in various countries on the commutation problem, as the many books, articles and discussions published at that time bear witness. One result of this was that the possibility was realised of neutralising self-induction and hastening the reversal of current in the short circuited coils by causing them to move in a commutating field, the strength of which was proportional to the load current of the machine. It was observed that this field could be obtained by placing commutating poles between the main poles and furnishing them with a winding through which the main current passed. Complete methods were worked out for the calculation of these poles. The year 1905 saw these ideas generally known and machines with interpoles being made in several localities. In 1905 Asea carried out a very complete test on a 4-pole machine of type L 150 having 4, 2, and 1 commutating poles and after that time they were often used on machines where commutating difficulties were to be expected, such as among others, the 5 motor generators supplied in 1907 to the Stockholm Electricity Works, which were each of 1,000 kW, 440—600 volts, 245 r.p.m., fig. 10. For tramway motors Asea was among the first firms to employ interpoles and the motors delivered in 1906 for the Jonkoping tramways were furnished with them.

With the production of "L" types came a time when the requirements of fixed brush position and sparkless commutation, even at heavy loads, greatly increased the necessity for interpoles, and these were more often fitted, especially as high voltages and speeds were more in demand. About 1910 it was found desirable to reconstruct, and standardise the whole series of DC machines anew, with special regard to the experience

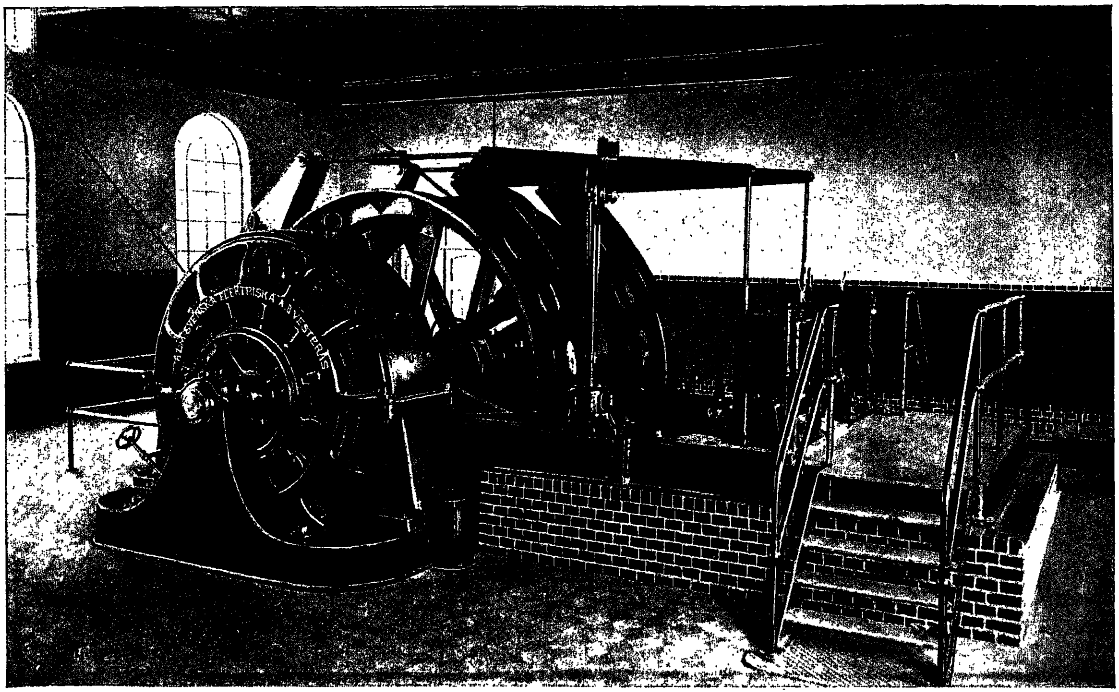


Fig. 16. Colliery winder at the Skanska Kolbrytnings A.B., Ormastorp, Sweden, 150 kW, 32 r.p.m.

gained during the preceding years with interpoles and the result was the "K" series, which embodies 50 types covering from 0.2 kW up to the largest outputs, figs. 11 and 12. With the smaller types, (with end shield bearings) and at first also with the larger types (with pedestal bearings), only half as many interpoles as main poles were used in order to save material, but it was soon shown to be economical to employ the full number of interpoles on account of the

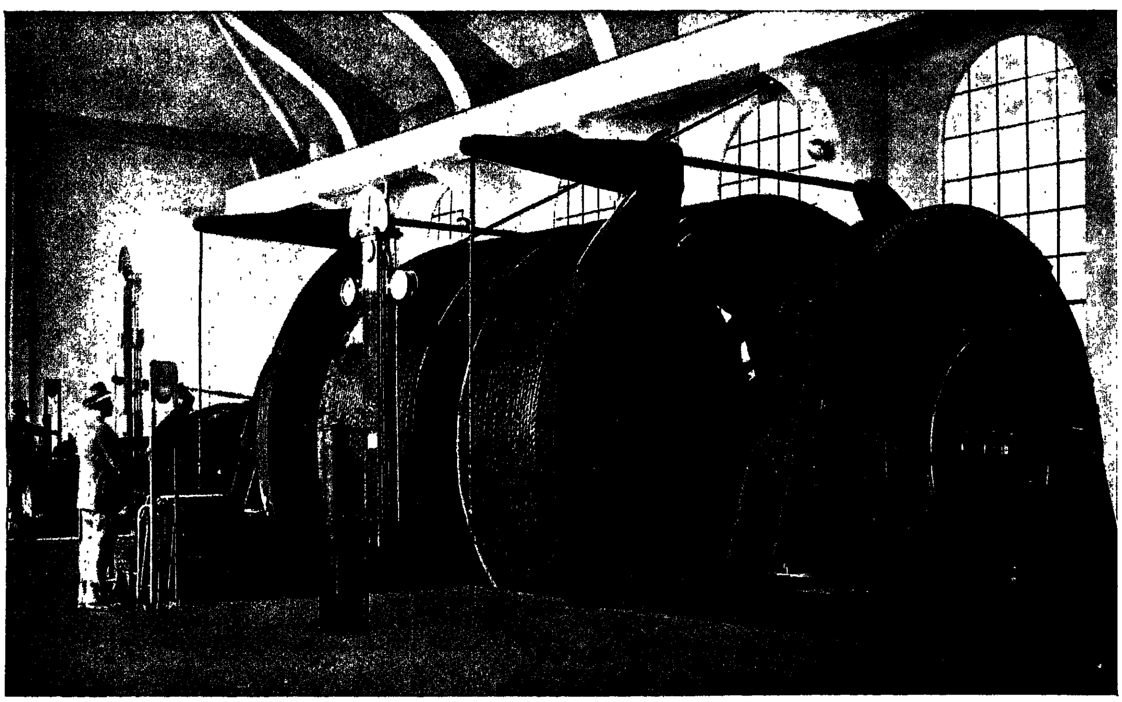


Fig. 17. Large colliery winder at Orkla Mines in Norway driven by two motors each 530 kW maximum, 30 r.p.m.

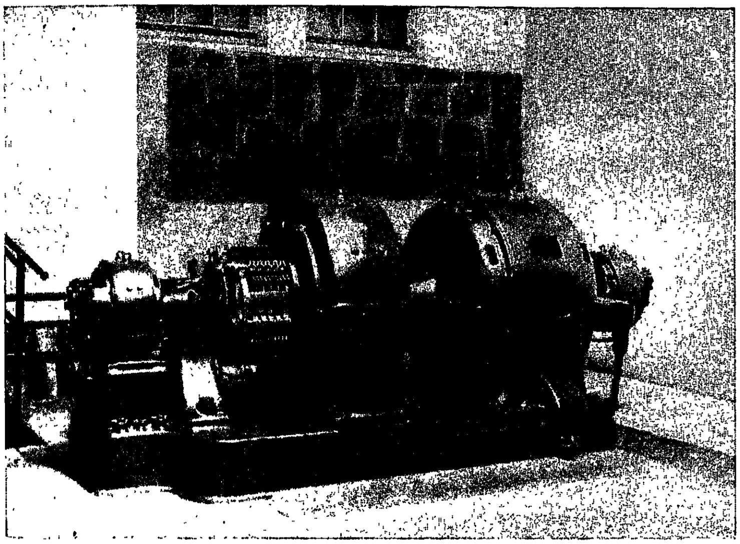


Fig. 18. Leonard set for paper machine motor at Hallsta Paper Mills, Sweden.

better commutation properties obtained (fig. 13), in certain cases in combination with compensating windings (fig. 14), which now came for the first time into their full rights and became of great significance.

A specially noteworthy installation was one at Domnarvet Iron Works, where the complete electrification was carried out in 1915 for a 750 mm reversible rolling mill. For this Asea supplied a motor generator with a 48 ton flywheel, fig. 15, and a reversible motor for a maximum load of 7000 kW, fig. 12, switchgear and auxiliaries. These machines are furnished with both commutating poles and compensating windings and have fulfilled all guarantees covering rapid reversing (at least 24 times per minute), high overload capacity and great dependability.

During the last few years further improvements have been made in the whole series of K types, in which the experience gained in the past 40 years has been applied to obtain truly first class machines with good characteristics and great dependability in operation.

Besides the more or less "normal" and standardised DC machines mentioned above, Asea has supplied year by year many generators and motors for installation where DC machines show advantages over AC on account of special characteristics. Considerations of space allow of only the most important of these special fields of use being shortly referred to, and illustrated by a few representative photographs.

It is chiefly the property of easy speed variation with well maintained efficiency which has enabled the DC shunt motor to be adopted with great advantage when very varying running requirements are in question. Speed regulation can either be obtained by varying the strength of the field (shunt regulation) or by varying the voltage supplied to the armature. In the latter case if there is a DC supply available at constant voltage a variable voltage can be obtained by connecting an auxiliary generator, the voltage of which can be altered, in series with the motor to be regulated ("buck and boost" principle). On the other hand if only AC is available an AC motor can be used to drive a DC generator whose voltage can be altered and which supplies current to the armature of the variable speed motor (Leonard principle); in this case also a simple equalising of large load variations can be obtained by using a flywheel with the motor generator set (Ilgner principle).

For colliery winders and reversing rolling mills the Leonard and Ilgner systems have been largely used and have chiefly made possible the large plants of this kind which have been

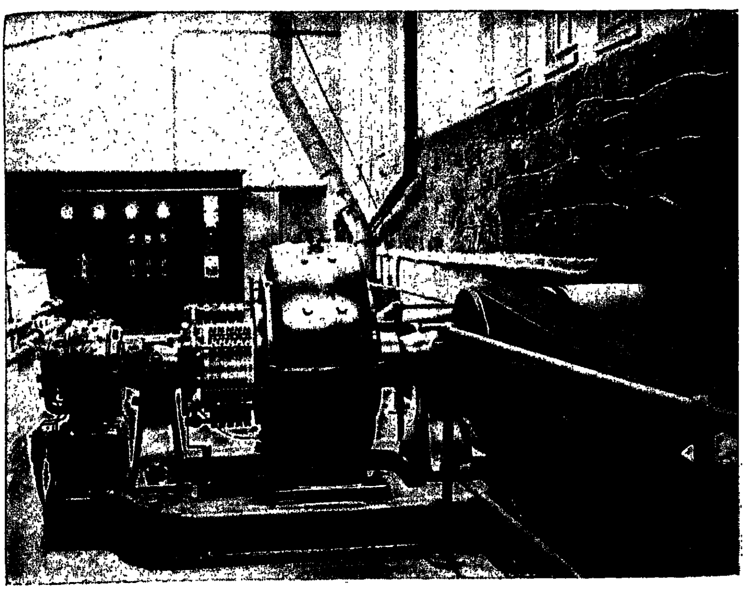


Fig. 19. Paper machine motor and switchgear at Hallsta Paper Mills, Sweden.

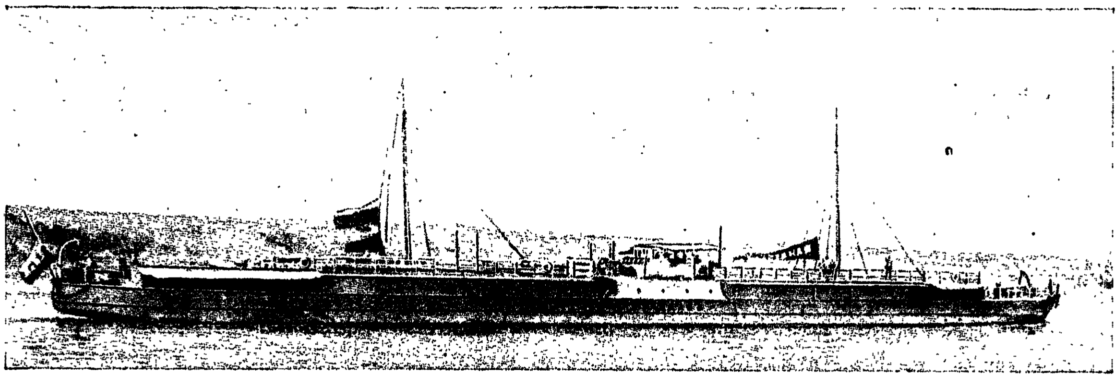


Fig. 20. Russian steamer Vandal owned by Nobel Bros, 1904.

turned out. Figs. 16 and 17 show some examples of colliery winders. The machines for the reversing rolling mills at Domnarvet Iron Works have already been referred to.

Another region in which the regulating methods described have been of great importance is in connection with the driving of machines used in paper manufacture and installed in paper mills. With these paper machines it is first of all necessary to be able to arrange to run at different speeds to suit the various kinds of paper being made and secondly when the most suitable speed has been obtained to maintain this constant for a considerable time. For this last requirement the shunt motor is very suitable when used in conjunction with an automatic regulator. As long ago as the middle '90s Asea furnished such plants with motors having shunt regulation. Later on shunt regulation was used in conjunction with a change over switch, arranged for two different voltages and "series parallel" connection of the motors two windings, and by this method a speed variation of 1:8 could be obtained at the motor. Soon however the advantages were realised of using generators with voltage regulation and in the last 20 years many installations have been supplied, both on the "buck and boost" and Leonard systems. Figs. 18 and 19 are two illustrations of a large paper mill employing driving motors dimensioned for 200 kW on the Leonard system.

The Leonard principle is also used for ship propulsion and was found particularly serviceable before satisfactory reversible internal combustion engines were constructed. Generators are driven continuously by internal combustion engines and the supply voltage is regulated as necessary, the power developed being taken to a motor coupled direct to the propeller shaft. Manœuvering and reversing is particularly simple and can be done direct from the bridge where the shunt resistance for the generator is placed. Fig. 20 shows one of three Russian vessels which were

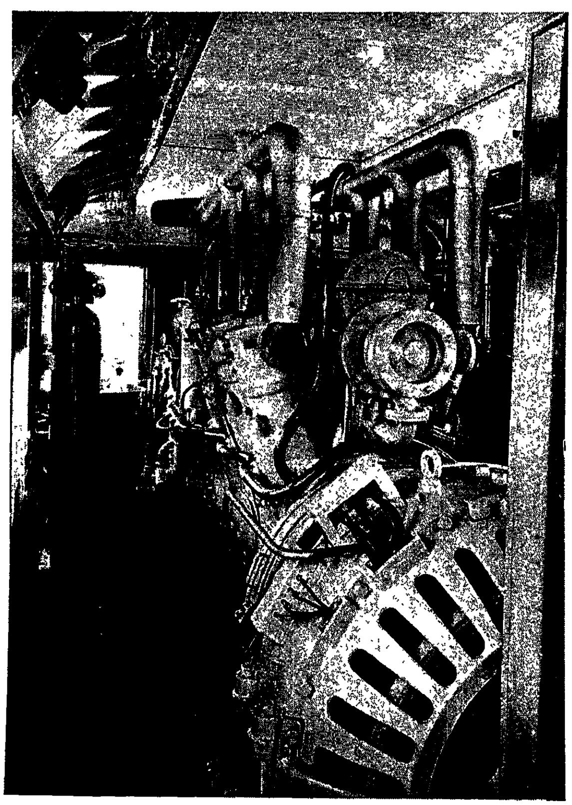


Fig. 21. Machinery compartment of 250 h.p. Diesel electric locomotive.

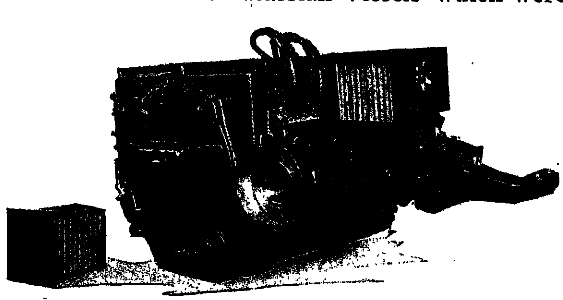


Fig. 22. Ventilated railway motor, 45 kW, with air filter.

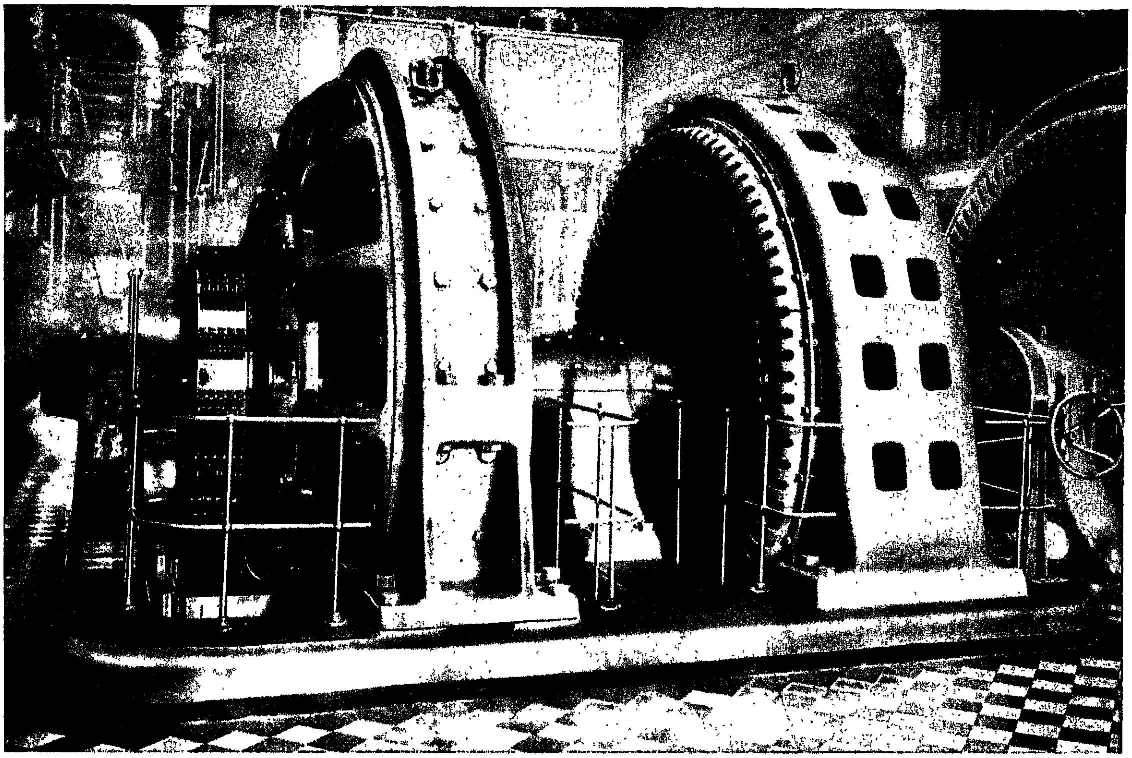


Fig. 23. 2,000 kW motor generator set at Gothenburg Electricity Works, Sweden.

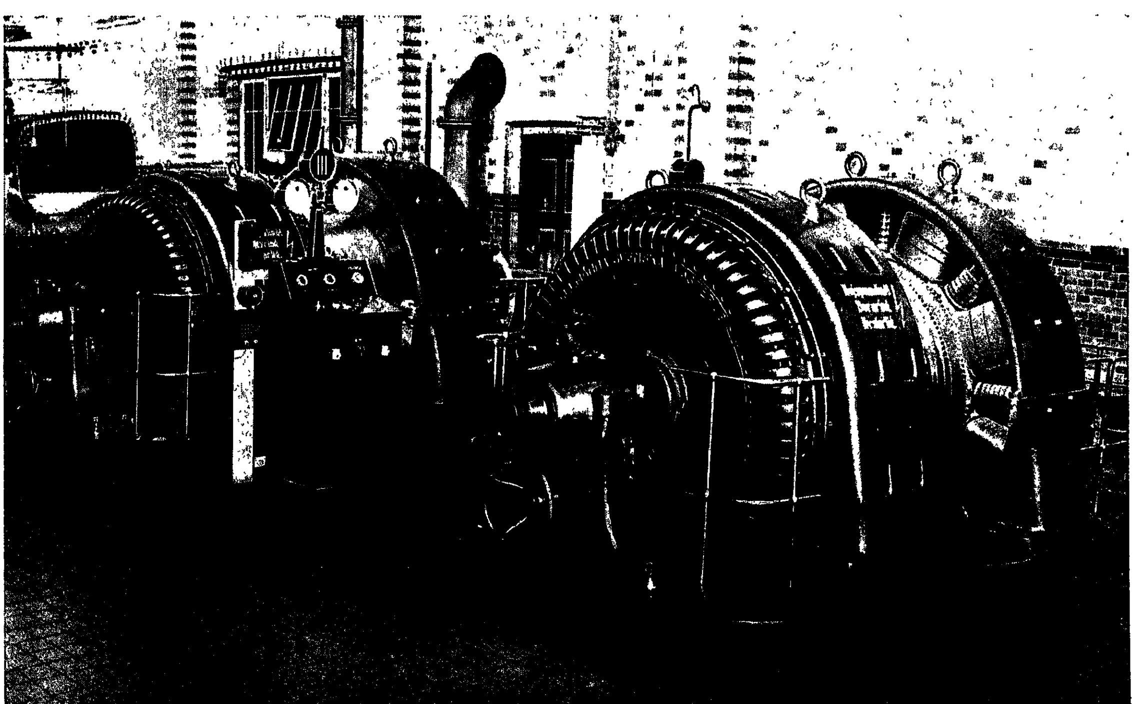


Fig. 24. Aarhus Electricity Works, Denmark, two cascade converters 1,000 kW.

equipped in 1904 with machinery of this kind. They were provided with three propeller shafts, the motors of which each absorb 80 kW.

In this connection may also be mentioned the system developed by Asea for power transmission in Diesel electric locomotives. The Diesel engine carried in the vehicle drives a DC generator, which is self-exciting and can be motored off the lighting battery for starting the engine. When running it supplies energy at variable voltage to motors coupled to the driving wheels. The motors are in this case series motors on account of the good properties possessed by this class of machine for railway work. Fig. 21 shows the machinery compartment of such a Diesel locomotive of 250 h.p. and fig. 22 a railway motor such as is used, and which generally resembles the motors usually employed in tramway and railway service.

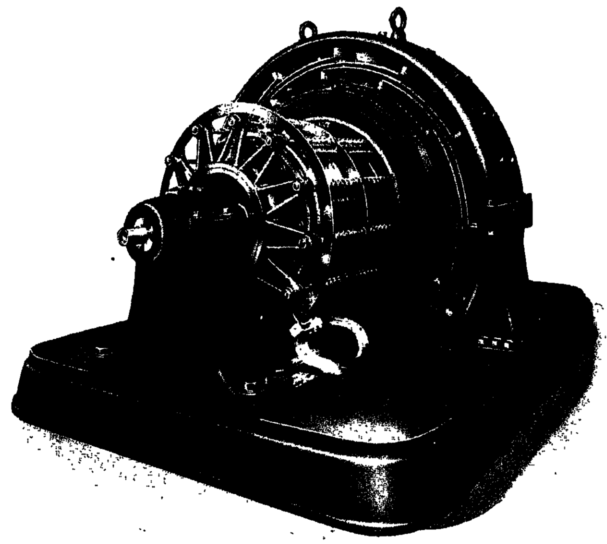


Fig. 25. 1,500 kW rotary converter for Norrkoping Electricity Works, Sweden.

For converting the power obtained from the large AC networks to DC at constant voltage, in electric power stations, factories and similar installations many large units, such as motor generators, cascade converters, and rotary converters have been produced. Space will not allow the development of these machines to be followed for instance on the lines of the increased speeds employed, but a few characteristic photographs are reproduced, *i. e.* a motor generator set for 2,000 kW in fig. 23, two cascade converters each of 1,000 kW in fig. 24 and a 1,500 kW rotary converter in fig. 25.

As a standby and also for smoothing out load variations accumulator batteries are used at converting stations in certain cases and these sometimes demand the installation of special DC ma-

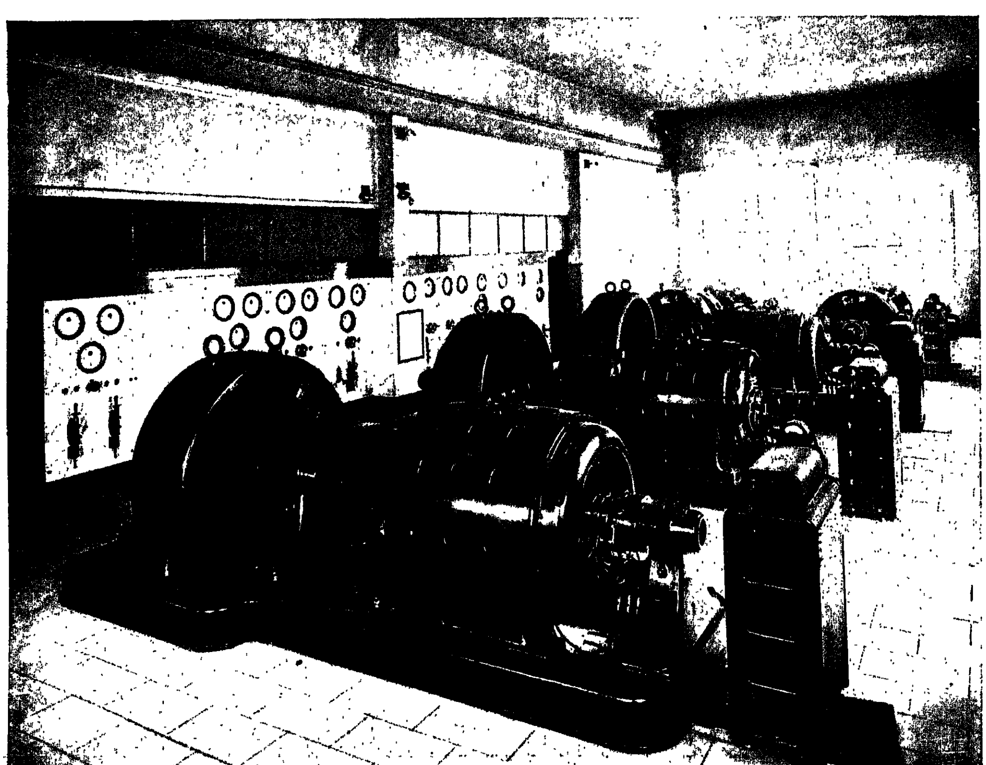


Fig. 26. Stockholm—Saltsjon Railway converter station, Sweden, 1,200 volts DC.

chines to regulate the charge and discharge of the battery. A case of special interest is that in which the machines are so arranged that the battery charge and discharge is automatically controlled, and this arrangement is suitable for plants where very rapid variations occur in the load. Fig. 27 shows machinery of this kind installed at Fagersta Bruk, with the object of making an accumulator battery take up the variations caused by a rolling mill in the load on the power station. The great advantage which is obtained is that the load on the power station is kept practically constant.

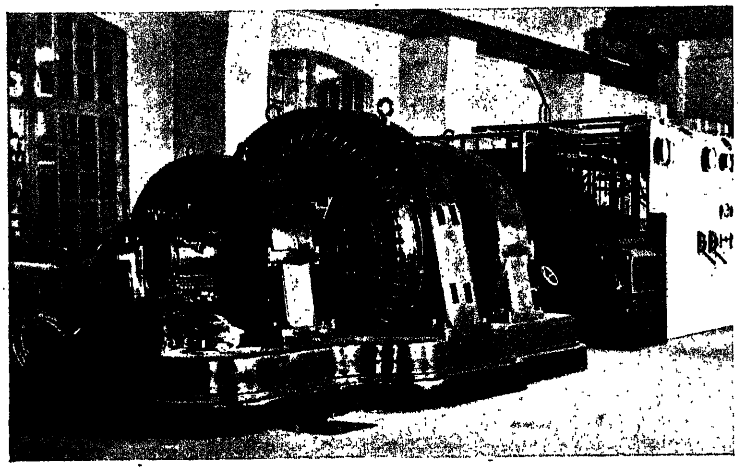


Fig. 27. Interior of Fagersta Bruks converter station, Sweden.

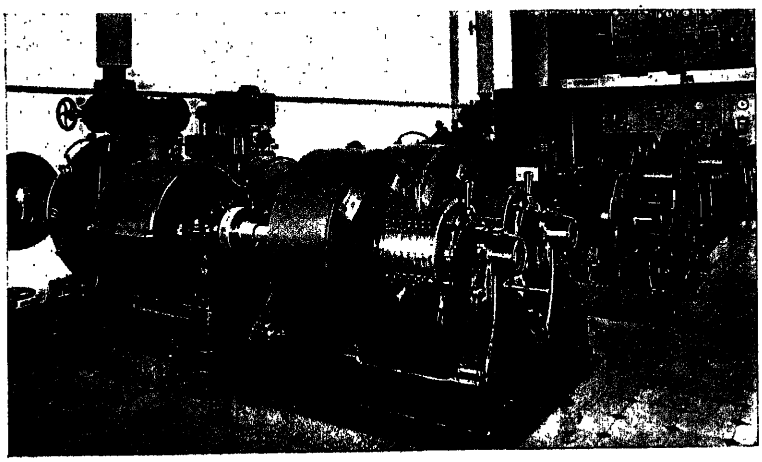


Fig. 28. Double generator installed in the Electricity Works at Cadiz, Spain.

In this connection it is well to recall the many complete installations supplied by Asea for driving tramways and light railways, chiefly designed for 600 volts and furnished with DC generators direct coupled to steam engines, or converters. Among these installations the Stockholm-Saltsjon railway occupies a noteworthy position. This line was electrified in 1913 on the DC system at 1,200 volts and Asea supplied the whole equipment of motor generators wound for 1,350 volts, fig. 26, automatic boosters for

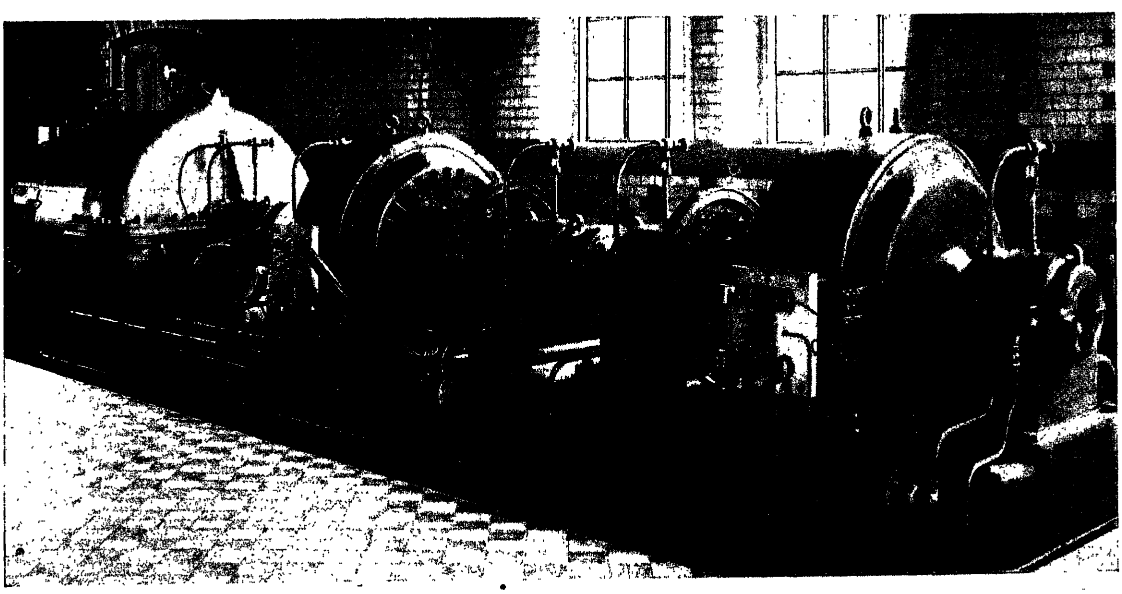


Fig. 29. 750 h.p. steam turbine direct coupled to two DC generators each of 250 kW, 2,000 r.p.m., 220 volts.

battery charge and discharge, and 8 bogie motor cars for 600 h.p., fig. 30.

Lastly special DC turbo generator sets may be referred to consisting of generators driven by high speed steam turbines. Twentyfive years ago when De Laval steam turbines were constructed for large outputs for the first time, the turbine speed was reduced by gearing to about 1,000 r.p.m. in two shafts, one arranged on each side of the turbine shaft, and a double generator was used, as shown in fig. 28. Later turbines were built for a speed of about 3,000 r.p.m. and direct coupled to generators (fig. 29). This speed is nevertheless exceedingly high for economical and favourable proportioning of DC machines and the tendency of later years accordingly has been to lower the turbine speed by the use of gearing. By this means a DC generator of normal design can be employed.

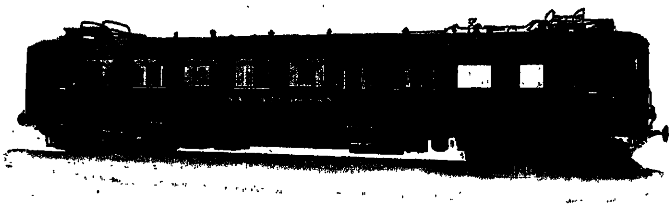


Fig. 30. Rail motor coach 600 h.p.

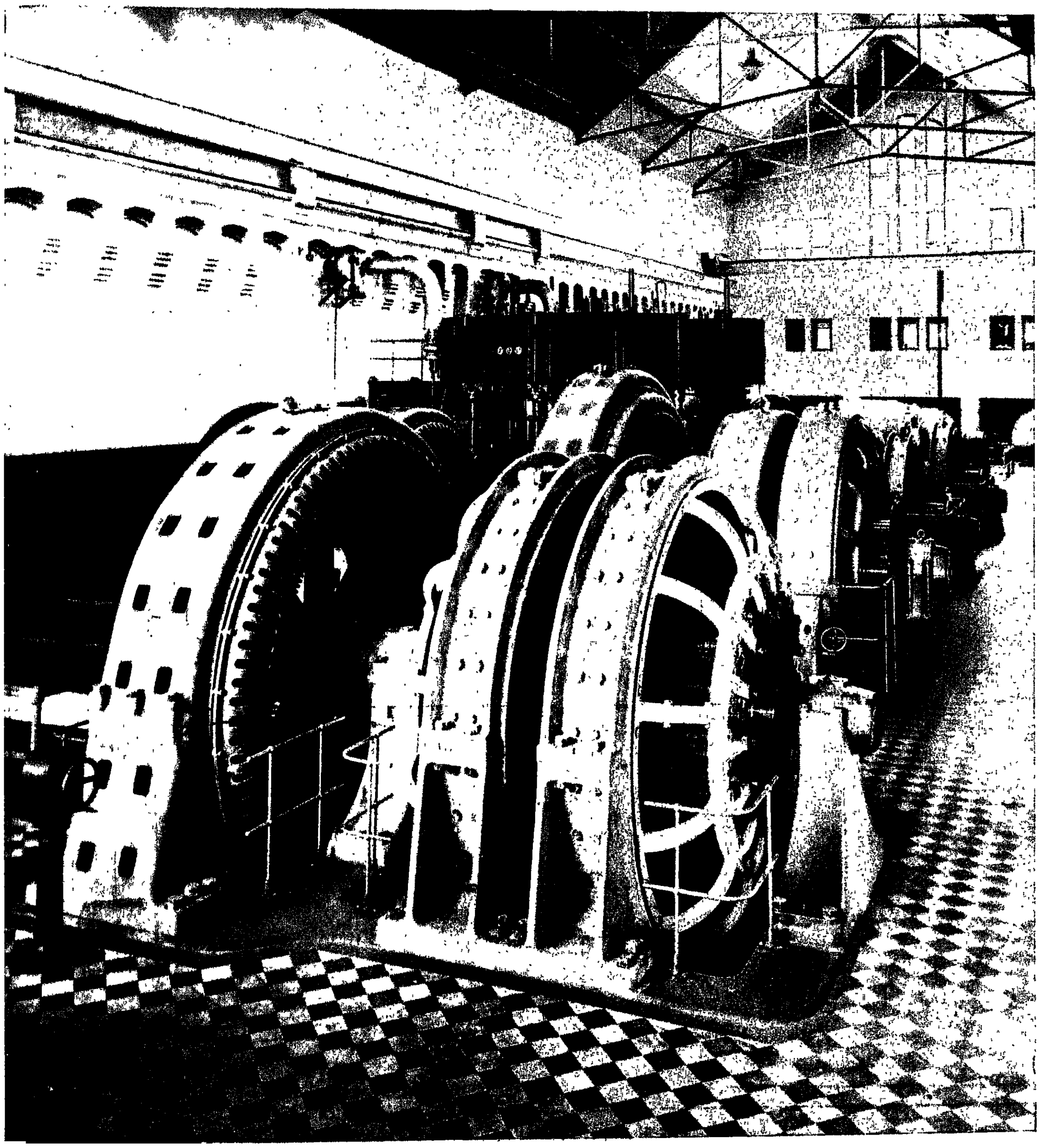
Vesterås 1924, Vestmanlands Allehanda Printing Co.

ASEA-JOURNAL

SWEDISH GENERAL ELECTRIC LTD
5, CHANCERY LANE—LONDON

...correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesteras, Sweden.
...is given to reprint articles or extracts from this journal, ...condition that the name — Asea-Journal — is clearly stated.

1924



Interior of power station at Gothenburg, Sweden, equipped with Asea motor generators.

ASEA'S CONTINUOUS CURRENT MACHINES.

When the company commenced work in the year 1883 the first machines built by Asea were DC machines. The construction of these was based upon the inventions patented by Jonas Wenstrom, who was at that time the Chief Engineer to the company. The most important and epoch making of the innovations introduced by him consisted in placing the armature windings in slots in the sheet iron stampings, of which the armature was built up, a principle which has since been used to an enormous extent in all kinds of electrical machinery. As regards their magnetic features these machines were "modern", having low pole cores and short magnetic flux paths. These early machines were characterised besides by their strength and solidity in mechanical respects, which was very marked by comparison both with foreign machines and with those turned out by Swedish competitors.

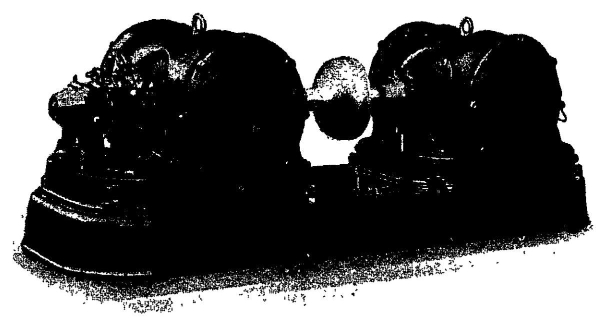


Fig. 1. DC machines of Wenstrom type.

The general appearance of these types, which were built between 1883 and 1886 in 9 sizes ranging from 0.9 to 23 kW can be gathered from the working drawing reproduced in fig. 2. Many of these machines are still in use.

Based on the experience gained with the foregoing, Wenstrom in 1889 constructed a second series of DC machines in 9 sizes between 1.65 and 44 kW. These were 4 pole machines. They possessed great overload capacity and were noteworthy for their particularly sound mechanical construction and their characteristic and striking appearance. They were built in very large numbers and became generally known as the "Wenstrom Well Known Type", fig. 1.

From 1880 these machines were supplied in great numbers for electric lighting plants in towns, factories, etc. only. From 1890 onwards, plants for the transmission and distribution of

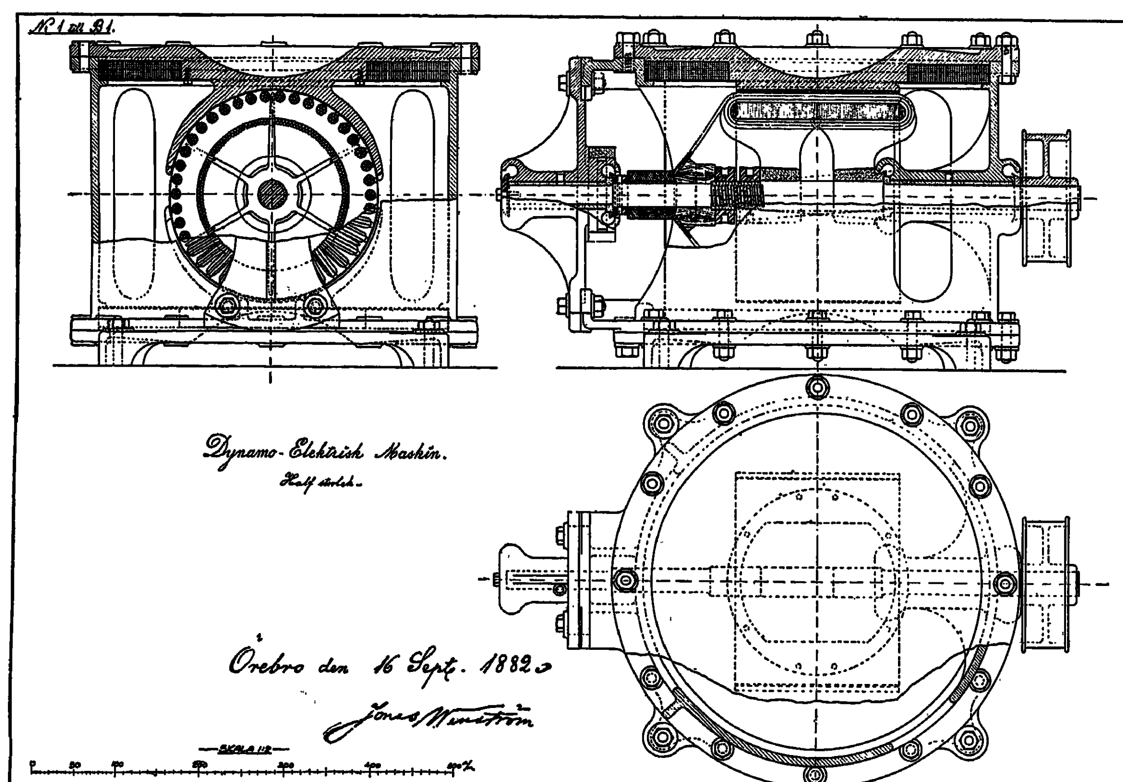


Fig. 2. Facsimile of a working drawing for dynamo type B No. 1.

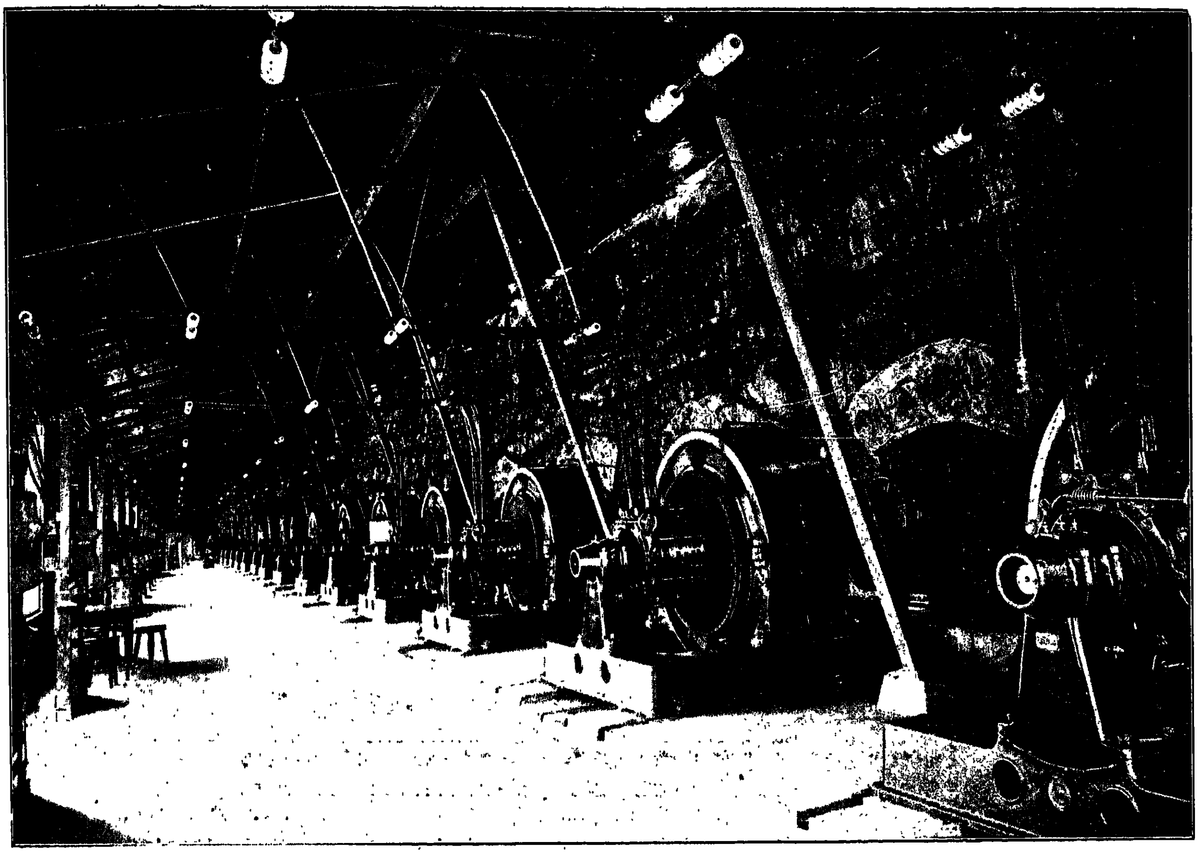


Fig. 3. Interior of the Stockholm Super-Phosphate Co. power station at Mansbo, Sweden, built in 1893—96.

power were equipped and the Wenstrom type found a further field of application. Several installations of this kind in connection with workshops, saw mills, paper mills etc. were laid down in Sweden, and a power transmission scheme from a 60 h.p. water turbine to a paper mill 3 km away at 1,300 volts DC may be specially mentioned. At the beginning of the '90s also, the first electric locomotive ever built in Sweden was supplied for use on a light railway at a wood pulp mill.

As will be seen from the illustrations, Wenstrom from the very first adopted the principle of construction with radial poles placed inside a circular yoke, which afterwards became standard all over the world for DC machines.

A number of different types of machines outside the standard series of Wenstrom dynamos were made, after the company had moved to the new workshops in Vesteras in 1892. This was necessary, partly because plants were put down for which the largest types in the standard series were inadequate, and partly as great efforts were made soon after 1890 to produce machines in larger sizes to correspond to the requirements of the time. The period was not a good one for the DC system, chiefly because the three phase system had just come to the front and in all quarters was absorbing the chief part of the interest. All effort and thought was transferred to the development of three phase machines and DC machines were put to some extent into the shade.

For electrolytic work however, the three phase system could not be used and this field was left open for the DC machine. The largest DC machines which Asea supplied during the '90s were made for this special work and may well be shortly referred to.

The chief plants of this kind were at Stockholm Super-phosphate Works at Mansbo, Dalelven, which was equipped in 1893 with 8 DC generators, each for 1,200 amps at 115 volts and 265 r.p.m., and in 1896 with a further 5 generators, each of 1,400 amps and 160 volts at 235 r.p.m. (fig. 3) and the Finish Electro-Chemical Co. at Imatra to which in 1898 5 generators were supplied, each for 2,000 amps at 110 volts and 133 r.p.m. (fig. 4).

The generators for the above installations and a number of lesser sizes were furnished with the armature winding patented by Sayers in 1891,

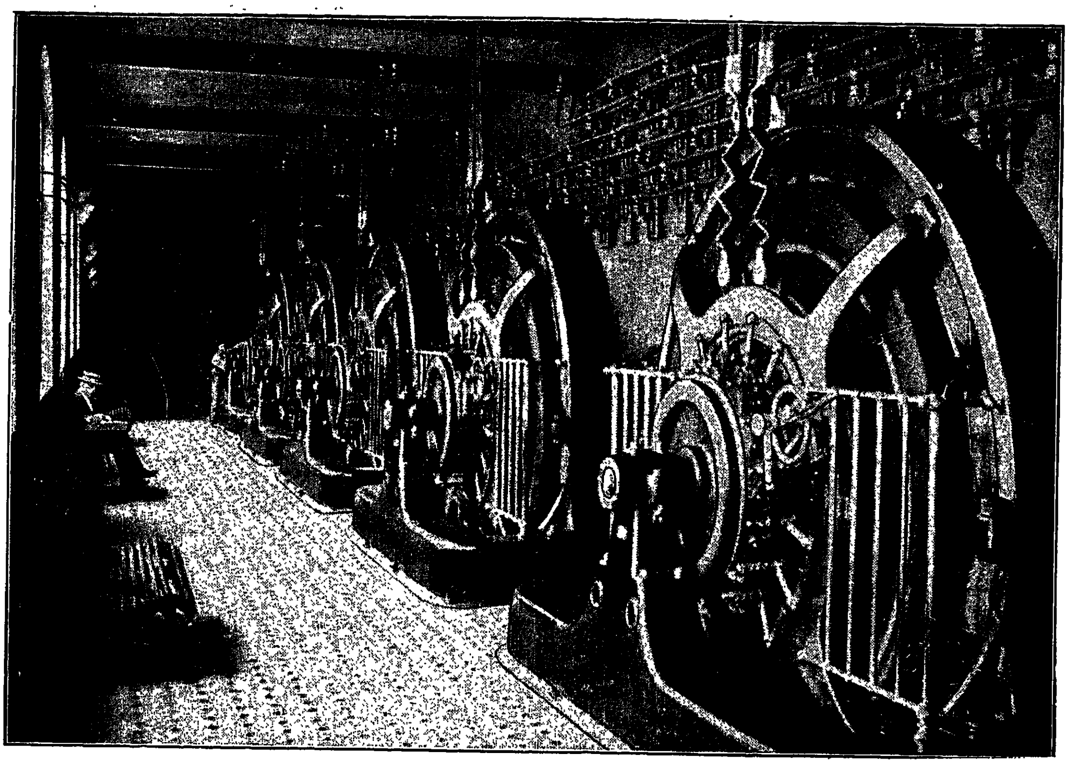


Fig. 4. Interior of the Finish Electro Chemical Co. power station at Imatra built in 1898.

with special commutating coils laid in the armature-slots, Asea having obtained the right to make use of this patent in Sweden. According to modern ideas the arrangement employed was not quite satisfactory, but at that time it was one of the best means known for overcoming the difficulties experienced in commutation in these large machines, which were moreover furnished with copper brushes, on account of the heavy current.

Another means of improving commutation was the compensating winding, which consisted of a winding carrying the main load current of the machine and placed in slots in the pole shoes. This principle was patented in 1884 by Menges and was experimented with by Ryan and Deri among others in 1893 and 1900 respectively, but did not come into its own until it was used at a later date in conjunction with commutating poles. During the '90s Asea built several machines with such windings; the first occasion being when the Stora Kopparbergs Bergslags Co. in 1896 placed an order for 8 motors, each of 30 h.p. at 300 volts and 550 r.p.m. for driving hoists for lifting charcoal to the

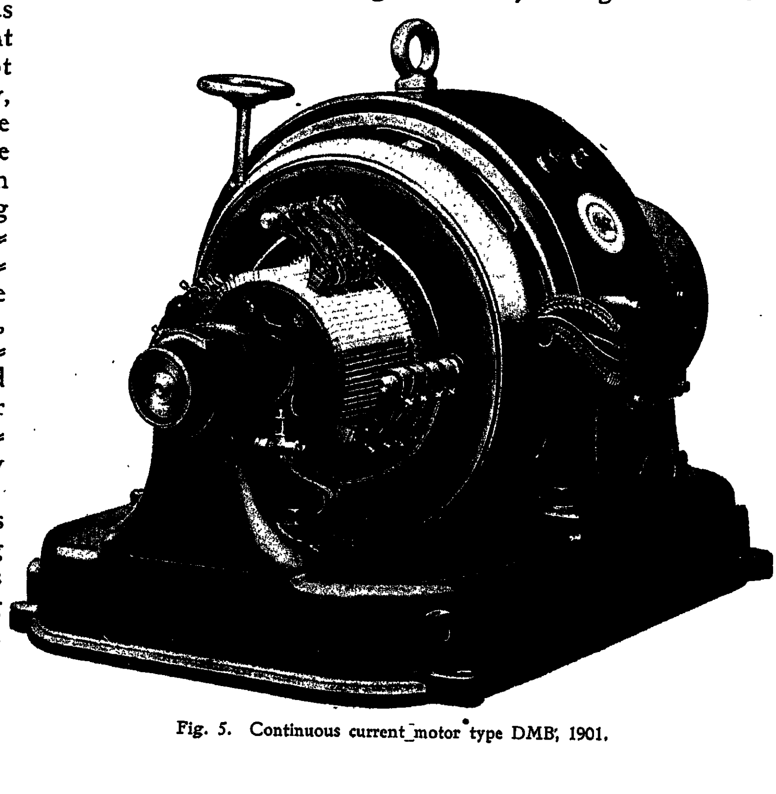


Fig. 5. Continuous current motor type DMB, 1901.

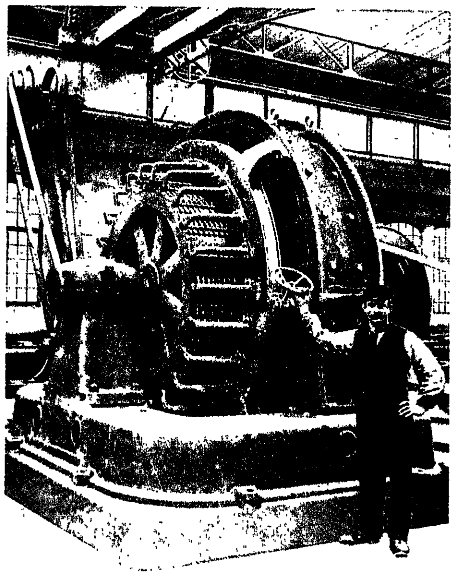


Fig. 6. 750 kW DC generator for Alby Chlorate Works, 1899.

furnaces at Domnarvet. This contract embodied the following requirements: "Only the slightest amount of sparking is to occur with the brushes in the neutral position, even should the current increase to 50 % above the normal. The brush gear and other details shall be so arranged that the direction of rotation can be changed quickly and without inconvenience. The machines to operate equally well in either direction and to be equipped with carbon brushes". To meet these requirements motors were built of the 4 pole type with laminated fields and with the salient poles provided with compensating winding, and with the shunt winding spread over the pole in the same slots as the compensating winding. (This last arrangement is embodied in Deri's patent of 1900.) One of these interesting motors is now in Asea's museum. The generators for this plant (330 volts, 400 amps, 300 r.p.m.) were also furnished with compensating windings. Another similar generator was delivered in 1898 to Tammerfors for 1,400 amps at 120 volts and 300 r.p.m. Of other machines which were constructed in the late '90s may be mentioned the "C" type, arranged for direct coupling to steam engines in central stations for lighting purposes and running at relatively low speeds. At this time also the smallest types were developed down to 0.2 h.p.

Although during this time Asea's designers put in the greater part of their work and interest on the development of the three phase machines they also spared time for the DC machines and their commutation problems. The result was not apparent by the production of any new series of machines (similar to the Wenstrom series) but was shown in the construction of the generators which were furnished for electrolytic purposes, which marked a considerable step forward in development. It must also be remembered that the arrangements made

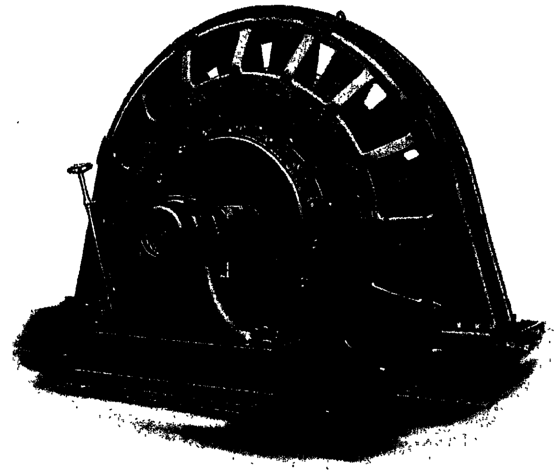


Fig. 7. DC generator, 1904.

in these machines for improving the commutation must be looked upon as research work. The proportion of the large machines was carefully considered and constituted a considerable advance in itself, as is demonstrated by the fact that the machines both at Mansbo and Imatra among others are still in every day use as also are some of the hoist motors at Domnarvet.

The large Wenstrom types were improved at the close of the '90s by being provided with

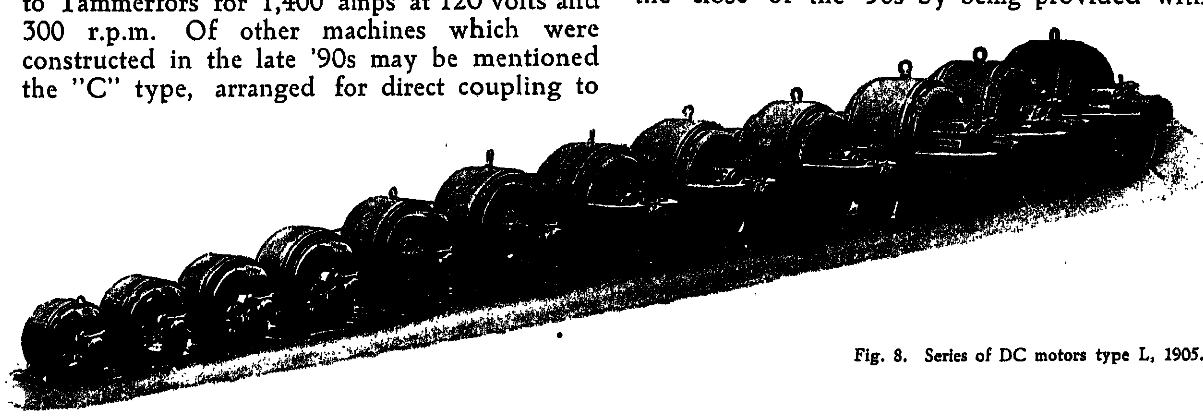


Fig. 8. Series of DC motors type L, 1905.

circular yokes of cast steel with radial poles all provided with field coils. Meanwhile as further improvements were shown to be necessary, a new series DMB-DLB was brought out in 1900—1902 in sizes from 10 to 300 kW. The outstanding features of this series were that the armature coils were former wound and laid in rectangular slots. The commutators were of larger diameter and provided with more segments than had been previously used, while carbon brushes were employed exclusively. The yoke, of cast steel, was circular and rested, together with the pedestal bearings, on a box bedplate (fig. 5). The poles were built up of laminations and secured to the yoke by screws. The brusholders were of a new pattern and were supported on brush spindles from a rocker ring fixed to the yoke. The air gap was relatively large, the ratio between the armature and field ampere turns well considered, so that as a result the machines behaved exceedingly well with regard to commutation, and at different loads only a very small amount of brush shifting was required.

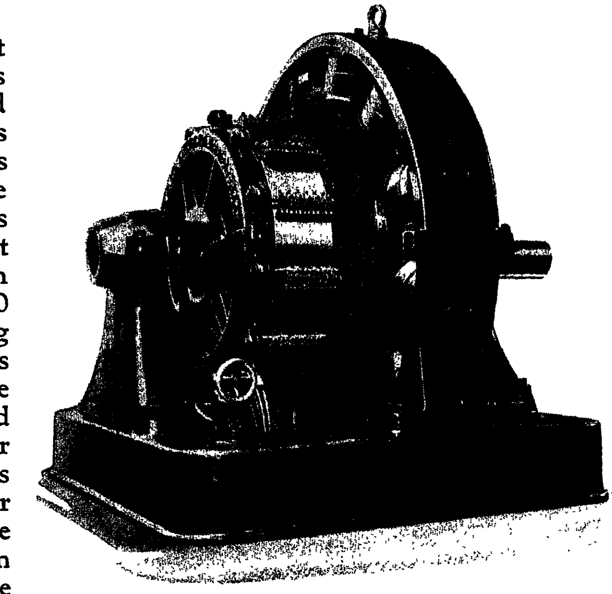


Fig. 9. DC generator type LD, 1906.

The most noteworthy large machines produced between the years 1899 and 1901 were three generators for Alby Chlorate Works, which were wound for 220 volts, 3,400 amps at 200 r.p.m. and provided with gauze brushes, fig. 6. These machines are still in use and during their many years service have worn out one or two sets of commutator segments. Two further generators supplied at this time were installed by the Stockholm Southern Tramways

Fig. 10. Interior of the Thule station of the Stockholm electricity works for which Asea in 1907 delivered five 1,000 kW motor generators.

Co., which were each for 165 kW at 575 volts and 150 r.p.m. with carbon brushes and small armature reaction, giving accordingly particularly good commutation.

It was after the critical industrial years 1901—1903, that the demand for DC machines first assumed such proportions that mass production could be considered for the smaller sizes. The reasons for the greater utilisation of the DC system, which was found by degrees to be comparable in its own domain with the AC system, are to be found in the increased demand and in the decided improvements which were made in the years immediately preceding. Power stations, especially in the large towns increased in size, following the introduction of satisfactory metallic filament lamps, also electric tramways were constructed; and as small industries developed to an ever increasing extent they found it more economical to purchase electric motive power from the central stations than to produce it in isolated plants. For these central station plants DC was found to be very suitable, chiefly on account of the certain, and immediately available, reserve which could be obtained by the installation of a storage battery. The DC system further found a most natural use in plants where continuous speed regulation was required, as in colliery winders, rolling mills, certain paper making machinery, etc. Of the striking improve-

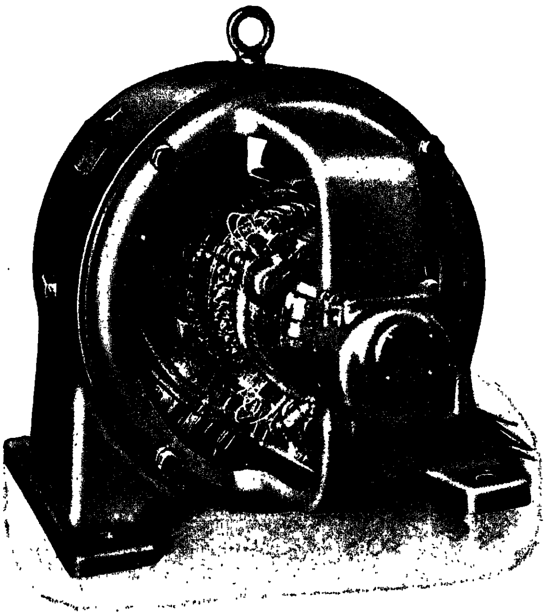


Fig. 11. DC machine type K.

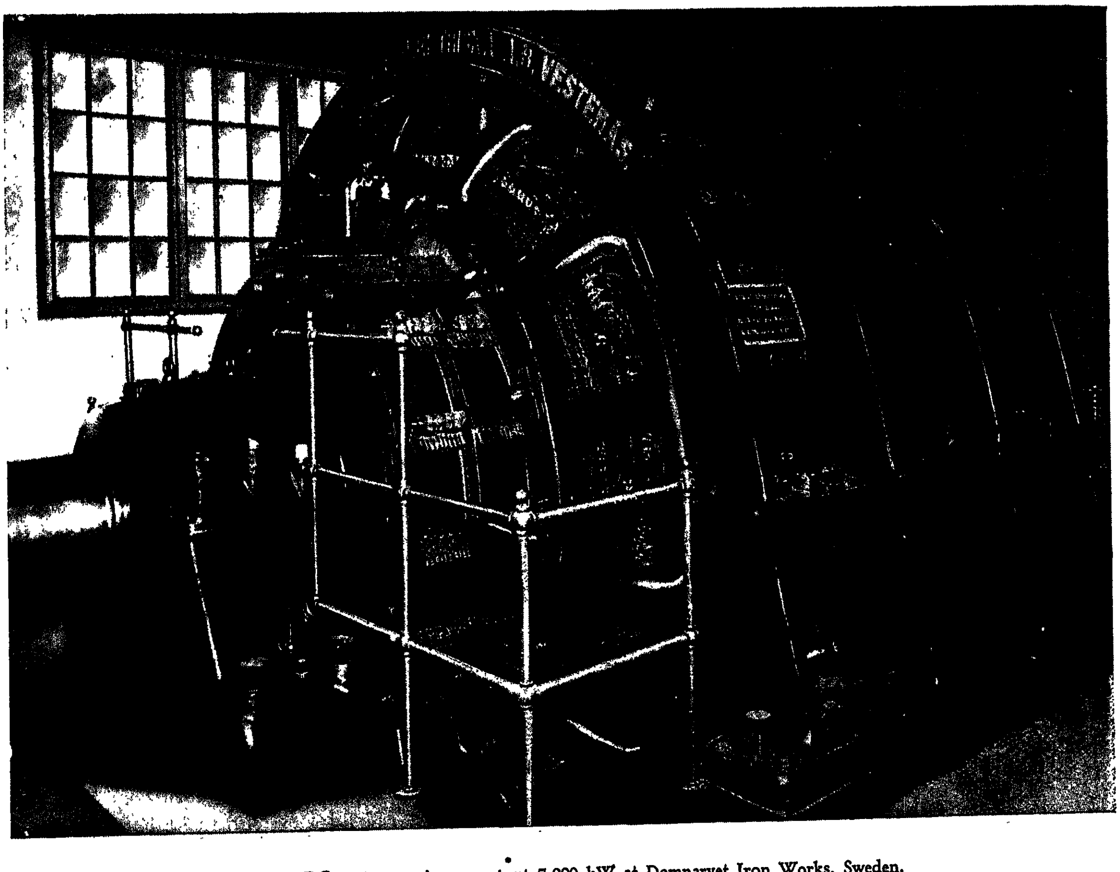


Fig. 12. DC motor maximum output 7,000 kW at Domnarvet Iron Works, Sweden.

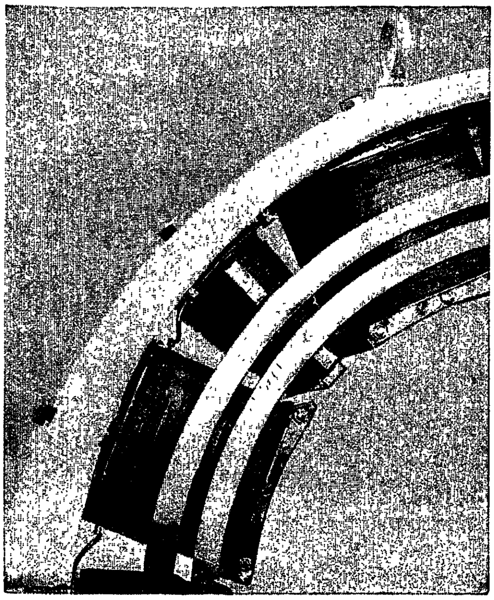


Fig. 13. Section of yoke with interpoles.

ments obtained by the use of interpoles more will be said further on.

In 1904 and the years immediately following Asea built many large machines for electric power stations in Gothenburg, Stockholm, Malmo, Uppsala, Jonkoping etc. as well as for various factories, fig. 7. Commutation continued to occasion considerable difficulty and thought, but as high speeds were not in demand designers were content to devote themselves to suitably dimensioning the pole shoes, providing a large air gap and using carbon brushes, points which in general ensured good operation, as brush shifting with varying loads was in general permitted. At this time also, methods of calculation and design were much improved, particularly in the direction of commutation.

The whole series of DC machines was at this time newly constructed and made more homogeneous, the different details being standardised to conform to the organisation of the shops on modern lines to meet the needs of mass production. This series of "L" types were made in 12 sizes from L 2, 0.5 kW to L 300, 60 kW and were constructed with circular yokes of cast steel, provided with supporting feet, large circular wrought iron poles, with laminated pole shoes, end bearing brackets and brush rockers carrying brush spindles fixed on the inside of the bearing, which construction was found to be cheapest and most suitable for production in quantities, fig. 8. The brushholders were of a new design, carbon brushes being used and made a sliding fit in the holders. Of these types large numbers were made during the years 1904—1912 and entirely displaced the earlier types of corresponding sizes.

The series was later extended by the addition of 5 sizes LD 400 to LD 800, arranged for direct coupling to steam engines, Diesel engines, and similar prime movers, running at a relatively low speed. These last machines were multipole and provided with pedestal bearings and bedplates, fig. 9.

The provision of interpoles for all sizes of DC machines constituted an epoch in development. The commutation problem was thereby for the time being definitely solved and good commutation was secured, which was quite independant of the strength and distribution of the main field, which made the use of DC machines possible under the most varying conditions of overload, and voltage and speed regulation.

As long ago as the close of the '80s Jonas Wenstrom had conducted research work with interpoles, (*i. e.* poles placed between the main poles and provided with windings through which the load current of the machine was circulated), on one of his machines. When the machine with this arrangement was tested it was reported that it did not run better than it had done before the interpoles were fitted and the matter

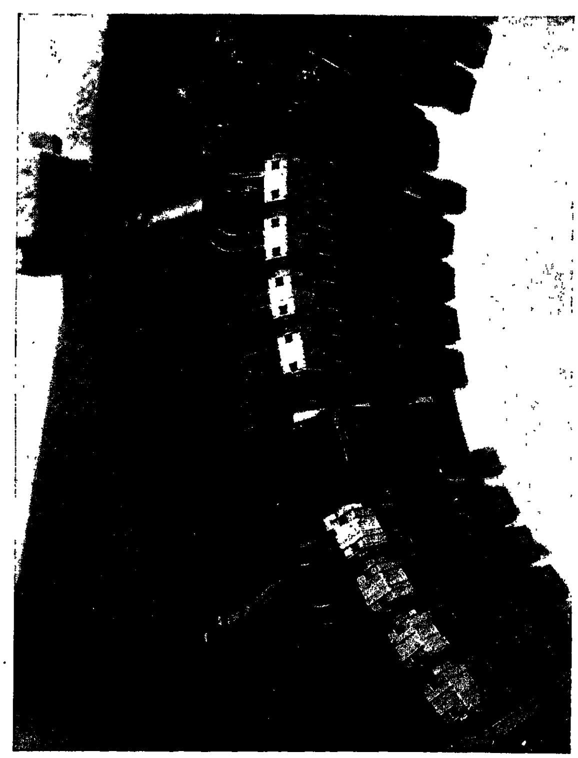


Fig. 14. Section of yoke with interpoles and compensating windings.

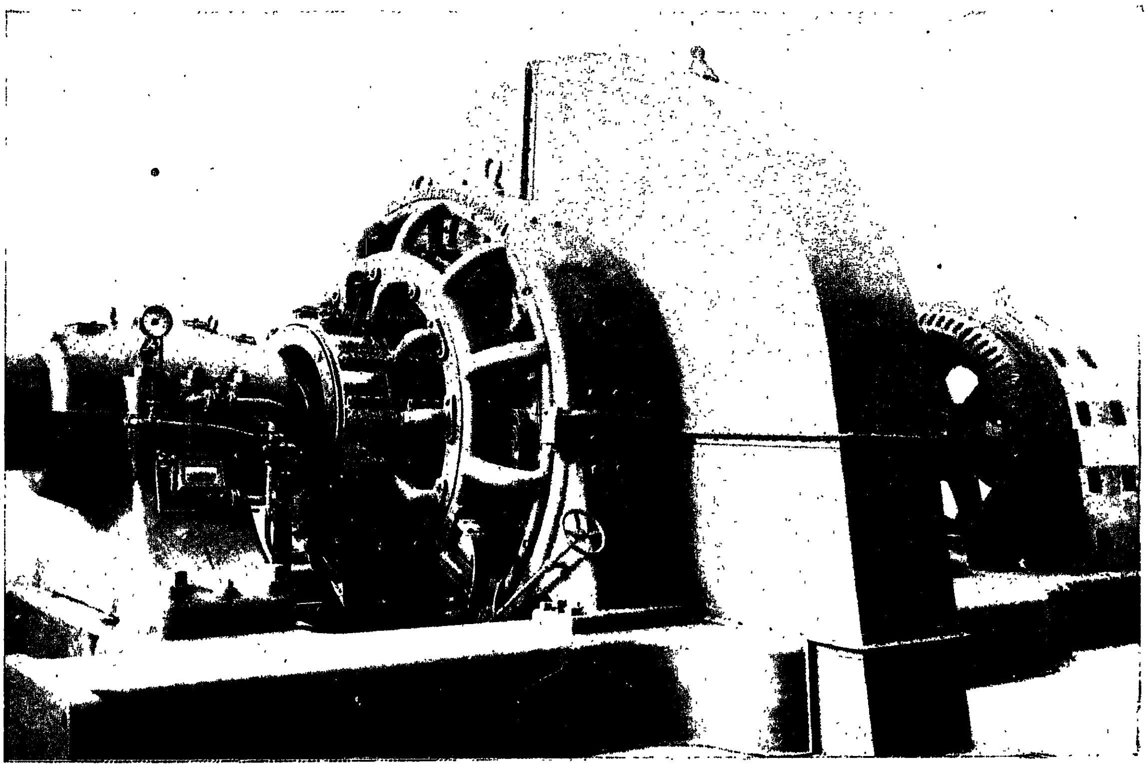


Fig. 15. Ilgner set at Domnarvet Iron Works, Sweden.

was allowed to drop without any further investigation, which is easily explained when one bears in mind that at that time the tests carried out on finished machines were not of a very searching character and also that the designing offices and shops were situated in different towns, so that they could not co-operate together particularly well in work of this kind.

Further research on interpoles was done in 1900 on a special type of motor provided with speed regulation for driving machine tools and the results were in this case judged to be very good, but as the manufacture of this particular type of motor was soon afterwards discontinued the idea of commutating poles was placed on one side, if not altogether forgotten.

The advent of the new century was marked by a great deal of work by technical men in various countries on the commutation problem, as the many books, articles and discussions published at that time bear witness. One result of this was that the possibility was realised of neutralising self-induction and hastening the reversal of current in the short circuited coils by causing them to move in a commutating field, the strength of which was proportional to the load current of the machine. It was observed that this field could be obtained by placing commutating poles between the main poles and furnishing them with a winding through which the main current passed. Complete methods were worked out for the calculation of these poles. The year 1905 saw these ideas generally known and machines with interpoles being made in several localities. In 1905 Asea carried out a very complete test on a 4-pole machine of type L 150 having 4, 2, and 1 commutating poles and after that time they were often used on machines where commutating difficulties were to be expected, such as among others, the 5 motor generators supplied in 1907 to the Stockholm Electricity Works, which were each of 1,000 kW, 440—600 volts, 245 r.p.m., fig. 10. For tramway motors Asea was among the first firms to employ interpoles and the motors delivered in 1906 for the Jonkoping tramways were furnished with them.

With the production of "L" types came a time when the requirements of fixed brush position and sparkless commutation, even at heavy loads, greatly increased the necessity for interpoles, and these were more often fitted, especially as high voltages and speeds were more in demand. About 1910 it was found desirable to reconstruct, and standardise the whole series of DC machines anew, with special regard to the experience

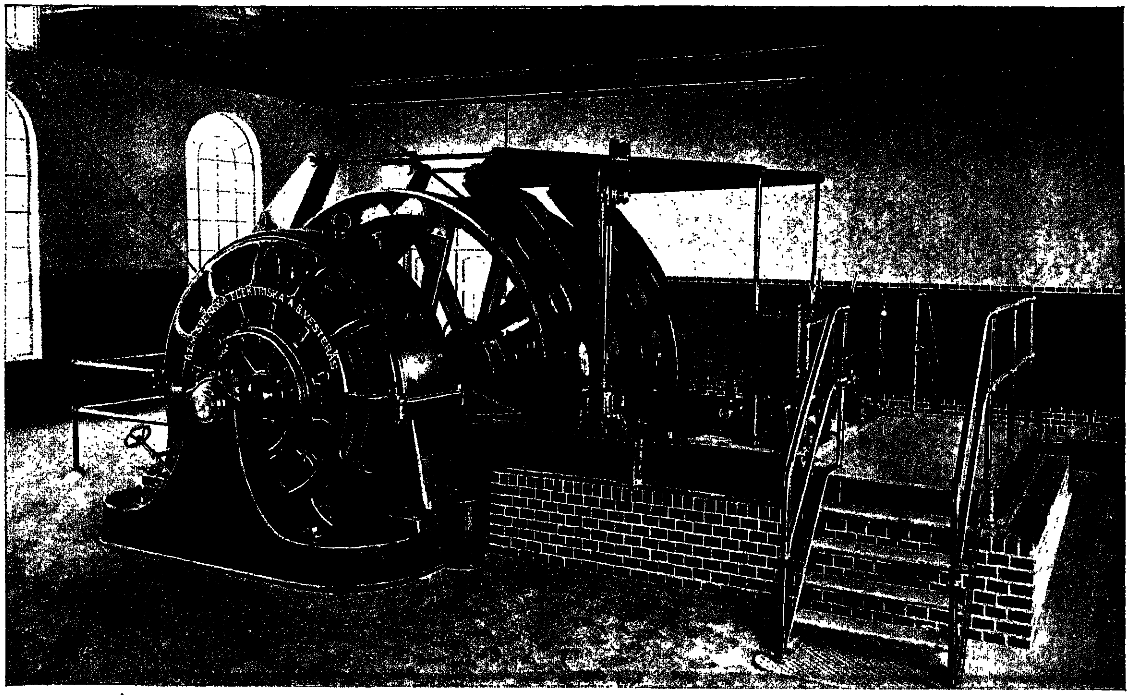


Fig. 16. Colliery winder at the Skanska Kolbrytnings A.B., Ormastorp, Sweden, 150 kW, 32 r.p.m.

gained during the preceding years with interpoles and the result was the "K" series, which embodies 50 types covering from 0.2 kW up to the largest outputs, figs. 11 and 12. With the smaller types, (with end shield bearings) and at first also with the larger types (with pedestal bearings), only half as many interpoles as main poles were used in order to save material, but it was soon shown to be economical to employ the full number of interpoles on account of the

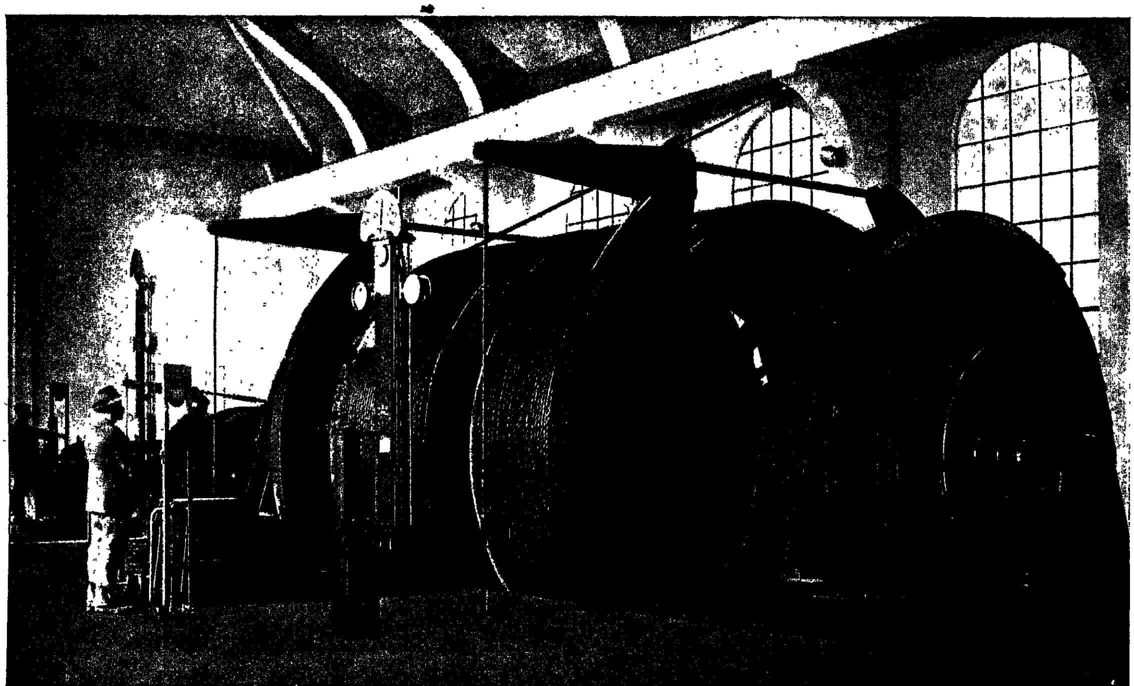


Fig. 17. Large colliery winder at Orkla Mines in Norway driven by two motors each 530 kW maximum, 30 r.p.m.

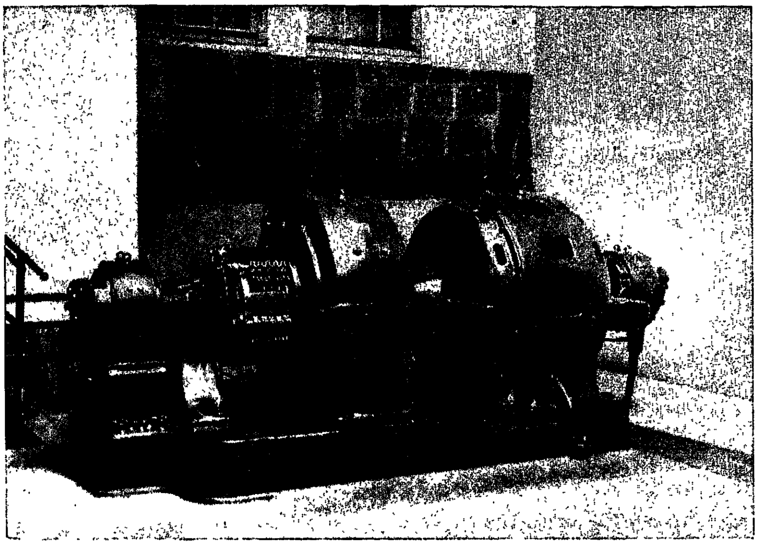


Fig. 18. Leonard set for paper machine motor at Hallsta Paper Mills, Sweden.

better commutation properties obtained (fig. 13), in certain cases in combination with compensating windings (fig. 14), which now came for the first time into their full rights and became of great significance.

A specially noteworthy installation was one at Domnarvet Iron Works, where the complete electrification was carried out in 1915 for a 750 mm reversible rolling mill. For this Asea supplied a motor generator with a 48 ton flywheel, fig. 15, and a reversible motor for a maximum load of 7000 kW, fig. 12, switchgear and auxiliaries. These machines are furnished with both commutating poles and compensating windings and have fulfilled all guarantees covering rapid reversing (at least 24 times per minute), high overload capacity and great dependability.

During the last few years further improvements have been made in the whole series of K types, in which the experience gained in the past 40 years has been applied to obtain truly first class machines with good characteristics and great dependability in operation.

Besides the more or less "normal" and standardised DC machines mentioned above, Asea has supplied year by year many generators and motors for installation where DC machines show advantages over AC on account of special characteristics. Considerations of space allow of only the most important of these special fields of use being shortly referred to, and illustrated by a few representative photographs.

It is chiefly the property of easy speed variation with well maintained efficiency which has enabled the DC shunt motor to be adopted with great advantage when very varying running requirements are in question. Speed regulation can either be obtained by varying the strength of the field (shunt regulation) or by varying the voltage supplied to the armature. In the latter case if there is a DC supply available at constant voltage a variable voltage can be obtained by connecting an auxiliary generator, the voltage of which can be altered, in series with the motor to be regulated ("buck and boost" principle). On the other hand if only AC is available an AC motor can be used to drive a DC generator whose voltage can be altered and which supplies current to the armature of the variable speed motor (Leonard principle); in this case also a simple equalising of large load variations can be obtained by using a flywheel with the motor generator set (Ilgner principle).

For colliery winders and reversing rolling mills the Leonard and Ilgner systems have been largely used and have chiefly made possible the large plants of this kind which have been

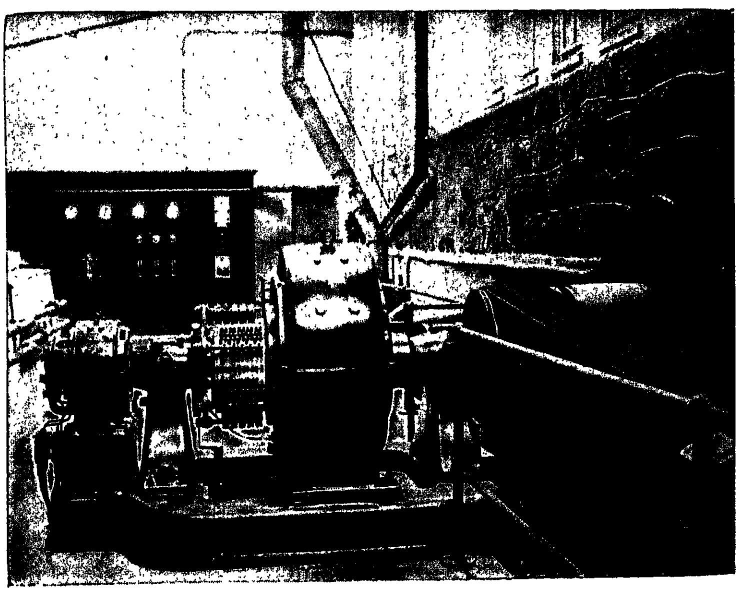


Fig. 19. Paper machine motor and switchgear at Hallsta Paper Mills, Sweden.

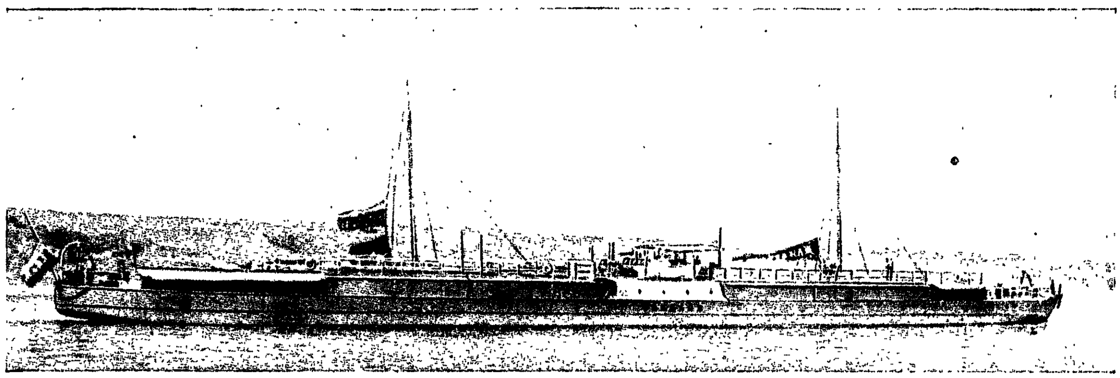


Fig. 20. Russian steamer Vandal owned by Nobel Bros, 1904.

turned out. Figs. 16 and 17 show some examples of colliery winders. The machines for the reversing rolling mills at Domnarvet Iron Works have already been referred to.

Another region in which the regulating methods described have been of great importance is in connection with the driving of machines used in paper manufacture and installed in paper mills. With these paper machines it is first of all necessary to be able to arrange to run at different speeds to suit the various kinds of paper being made and secondly when the most suitable speed has been obtained to maintain this constant for a considerable time. For this last requirement the shunt motor is very suitable when used in conjunction with an automatic regulator. As long ago as the middle '90s Asea furnished such plants with motors having shunt regulation. Later on shunt regulation was used in conjunction with a change over switch, arranged for two different voltages and "series parallel" connection of the motors two windings, and by this method a speed variation of 1:8 could be obtained at the motor. Soon however the advantages were realised of using generators with voltage regulation and in the last 20 years many installations have been supplied, both on the "buck and boost" and Leonard systems. Figs. 18 and 19 are two illustrations of a large paper mill employing driving motors dimensioned for 200 kW on the Leonard system.

The Leonard principle is also used for ship propulsion and was found particularly serviceable before satisfactory reversible internal combustion engines were constructed. Generators are driven continuously by internal combustion engines and the supply voltage is regulated as necessary, the power developed being taken to a motor coupled direct to the propeller shaft. Manœuvering and reversing is particularly simple and can be done direct from the bridge where the shunt resistance for the generator is placed. Fig. 20 shows one of three Russian vessels which were

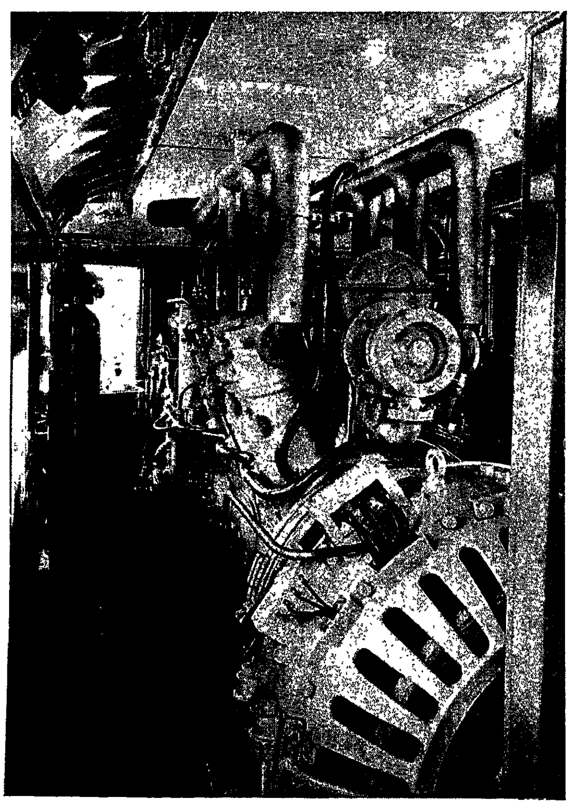


Fig. 21. Machinery compartment of 250 h.p. Diesel electric locomotive.

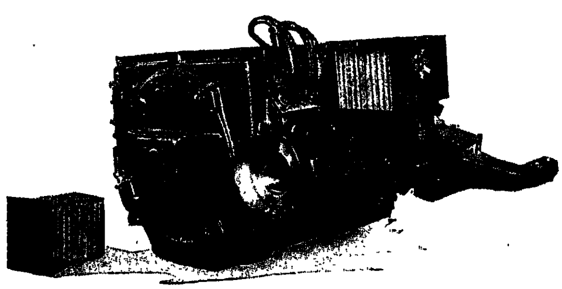


Fig. 22. Ventilated railway motor, 45 kW, with air filter.

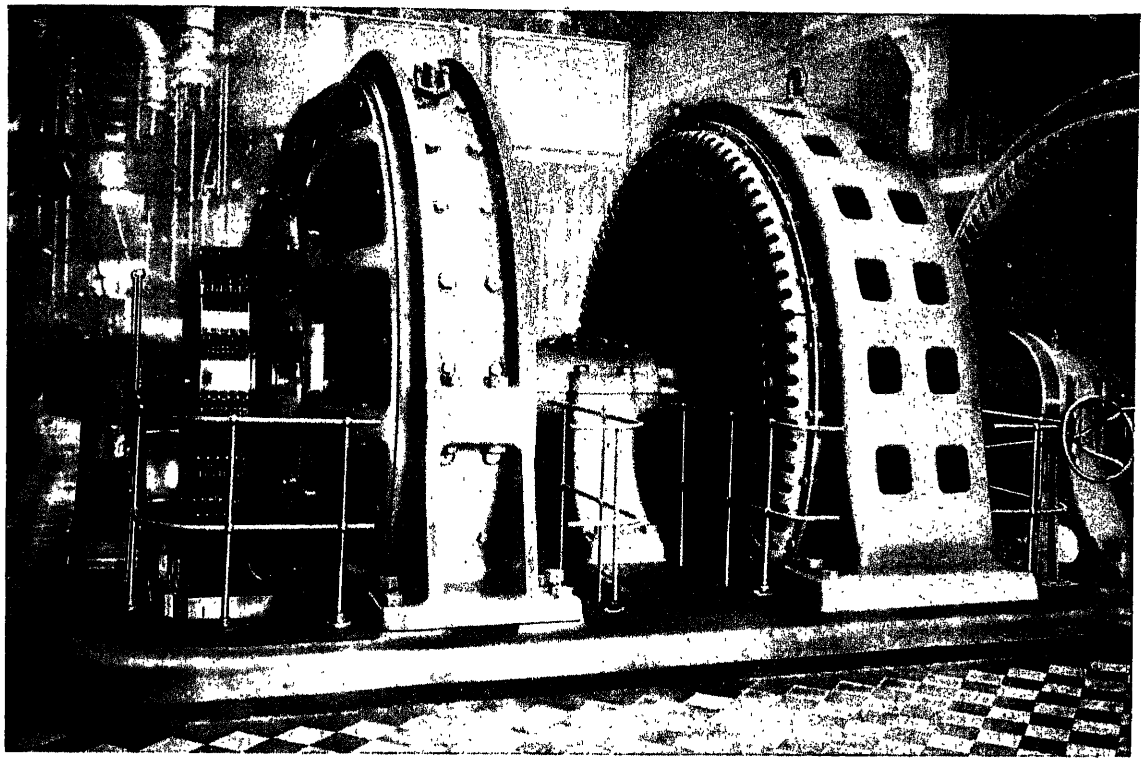


Fig. 23. 2,000 kW motor generator set at Gothenburg Electricity Works, Sweden.

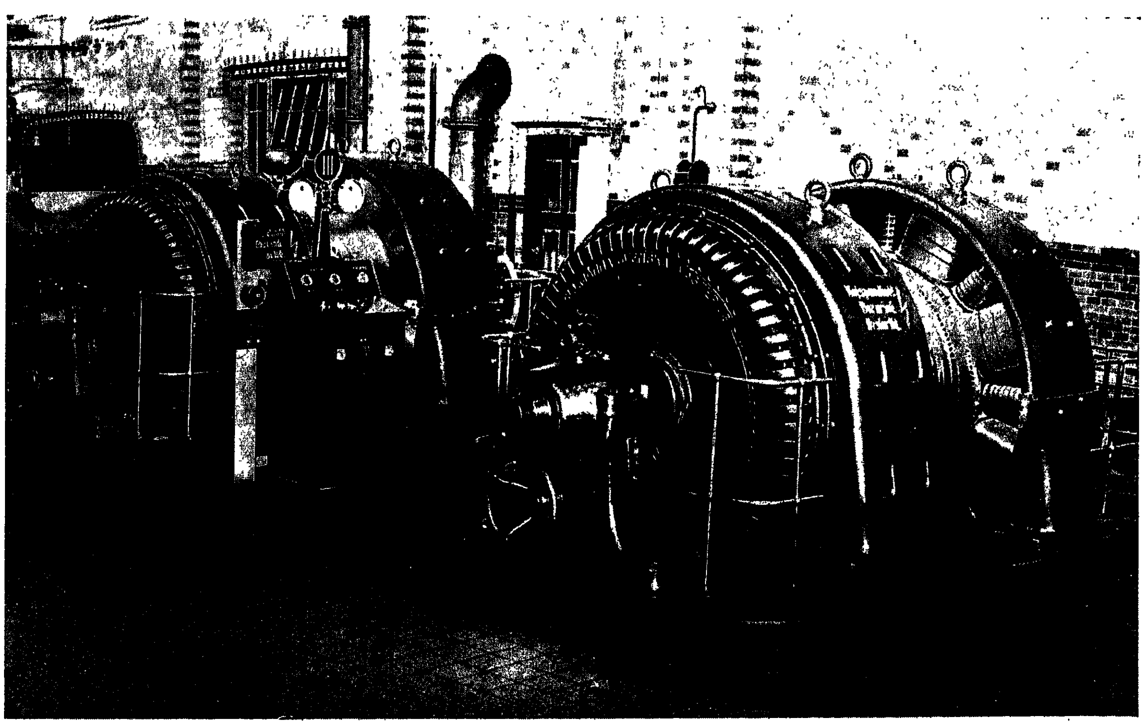


Fig. 24. Aarhus Electricity Works, Denmark, two cascade converters 1,000 kW.

equipped in 1904 with machinery of this kind. They were provided with three propeller shafts, the motors of which each absorb 80 kW.

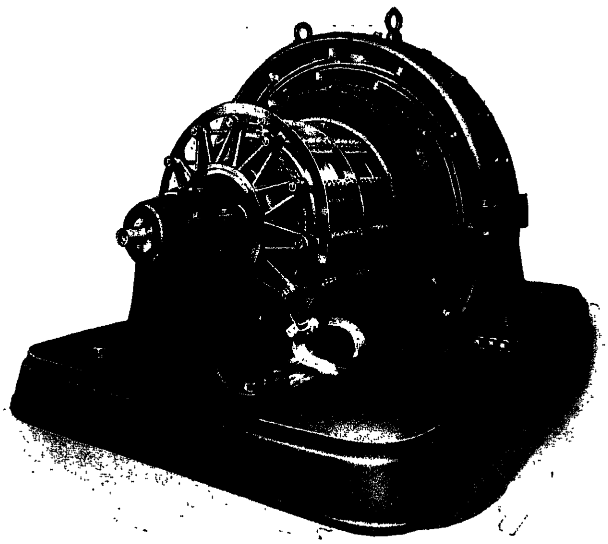


Fig. 25. 1,500 kW rotary converter for Norrkoping Electricity Works, Sweden.

In this connection may also be mentioned the system developed by Asea for power transmission in Diesel electric locomotives. The Diesel engine carried in the vehicle drives a DC generator, which is self-exciting and can be motored off the lighting battery for starting the engine. When running it supplies energy at variable voltage to motors coupled to the driving wheels. The motors are in this case series motors on account of the good properties possessed by this class of machine for railway work. Fig. 21 shows the machinery compartment of such a Diesel locomotive of 250 h.p. and fig. 22 a railway motor such as is used, and which generally resembles the motors usually employed in tramway and railway service.

For converting the power obtained from the large AC networks to DC at constant voltage, in electric power stations, factories and similar installations many large units, such as motor generators, cascade converters, and rotary converters have been produced. Space will not allow the development of these machines to be followed for instance on the lines of the increased speeds employed, but a few characteristic photographs are reproduced, *i. e.* a motor generator set for 2,000 kW in fig. 23, two cascade converters each of 1,000 kW in fig. 24 and a 1,500 kW rotary converter in fig. 25.

As a standby and also for smoothing out load variations accumulator batteries are used at converting stations in certain cases and these sometimes demand the installation of special DC ma-

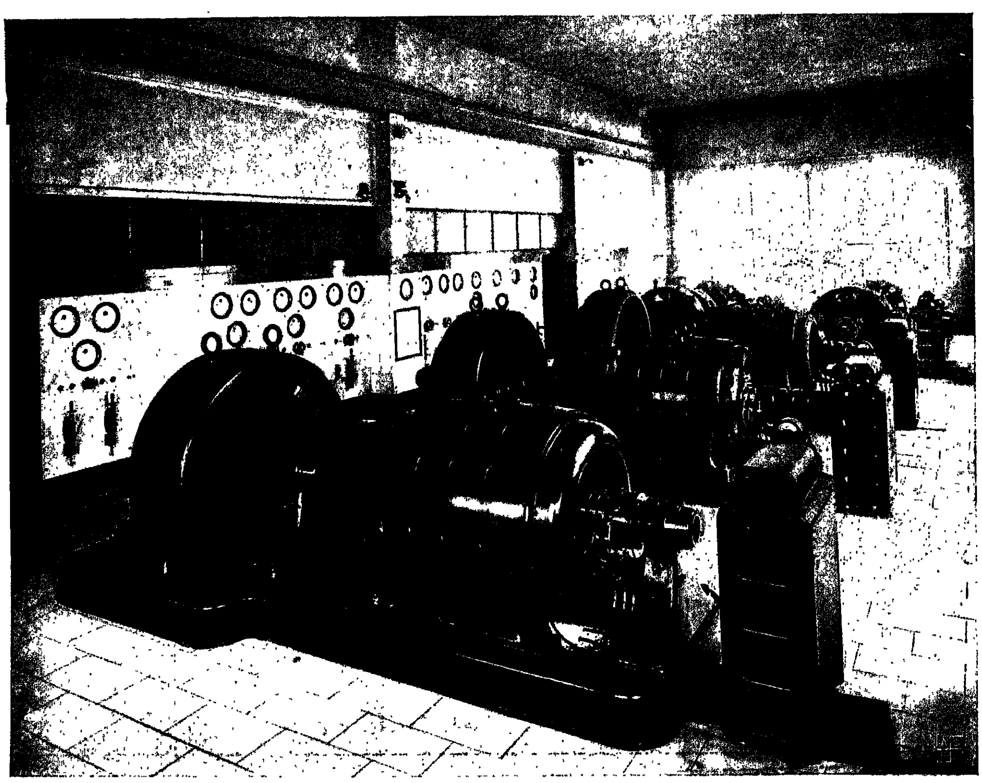


Fig. 26. Stockholm—Saltsjon Railway converter station, Sweden, 1,200 volts DC.

chines to regulate the charge and discharge of the battery. A case of special interest is that in which the machines are so arranged that the battery charge and discharge is automatically controlled, and this arrangement is suitable for plants where very rapid variations occur in the load. Fig. 27 shows machinery of this kind installed at Fagersta Bruk, with the object of making an accumulator battery take up the variations caused by a rolling mill in the load on the power station. The great advantage which is obtained is that the load on the power station is kept practically constant.

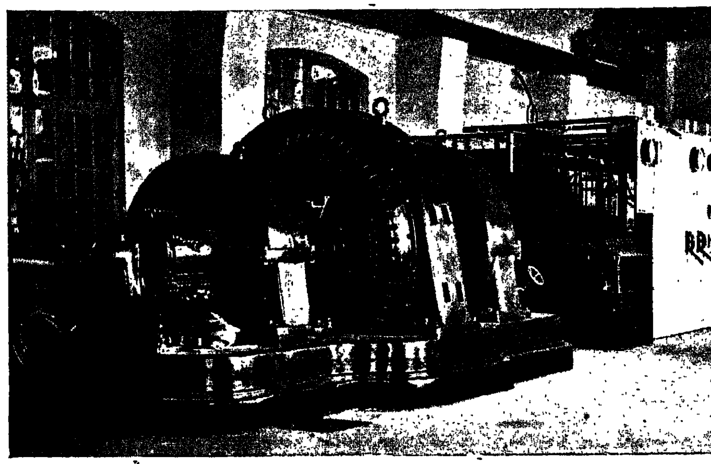


Fig. 27. Interior of Fagersta Bruks converter station, Sweden.

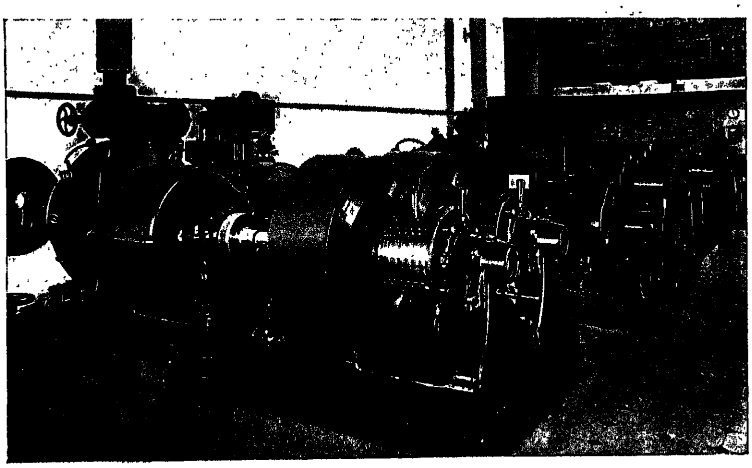


Fig. 28. Double generator installed in the Electricity Works at Cadiz, Spain.

In this connection it is well to recall the many complete installations supplied by Asea for driving tramways and light railways, chiefly designed for 600 volts and furnished with DC generators direct coupled to steam engines, or converters. Among these installations the Stockholm-Saltsjon railway occupies a noteworthy position. This line was electrified in 1913 on the DC system at 1,200 volts and Asea supplied the whole equipment of motor generators wound for 1,350 volts, fig. 26, automatic boosters for

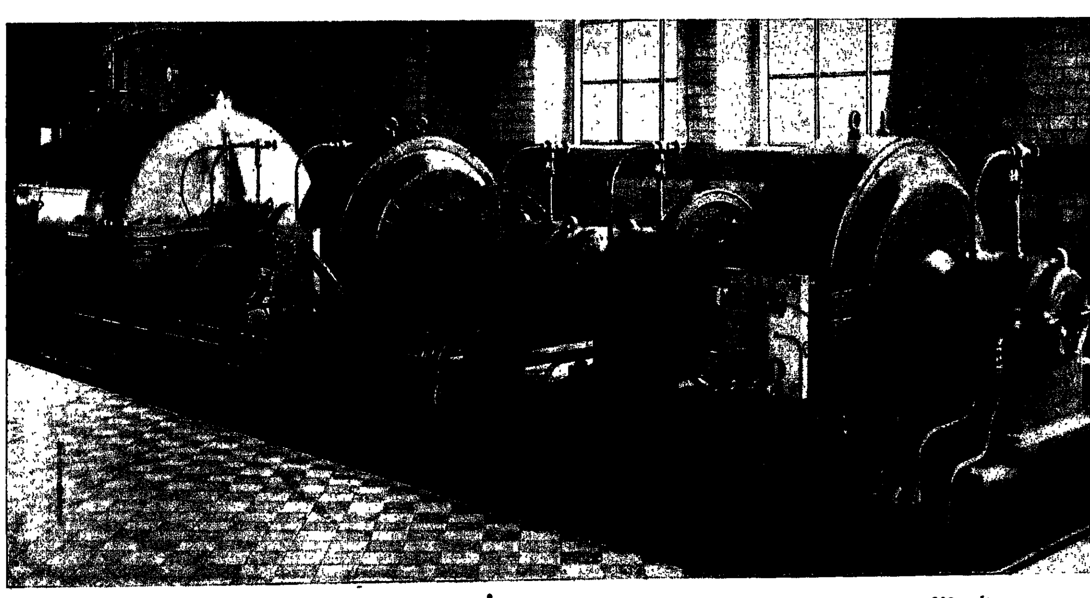


Fig. 29. 750 h.p. steam turbine direct coupled to two DC generators each of 250 kW, 2,000 r.p.m., 220 volts.

battery charge and discharge, and 8 bogie motor cars for 600 h.p., fig. 30.

Lastly special DC turbo generator sets may be referred to consisting of generators driven by high speed steam turbines. Twentyfive years ago when De Laval steam turbines were constructed for large outputs for the first time, the turbine speed was reduced by gearing to about 1,000 r.p.m. in two shafts, one arranged on each side of the turbine shaft, and a double generator was used, as shown in fig. 28. Later turbines were built for a speed of about 3,000 r.p.m. and direct coupled to generators (fig. 29). This speed is nevertheless exceedingly high for economical and favourable proportioning of DC machines and the tendency of later years accordingly has been to lower the turbine speed by the use of gearing. By this means a DC generator of normal design can be employed.

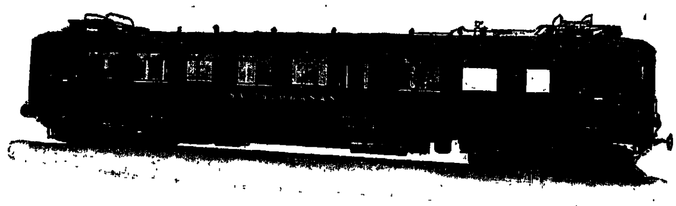


Fig. 30. Rail motor coach 600 h.p.

Vesterås 1924, Vestmanlands Allehanda Printing Co.

ASEA-JOURNAL

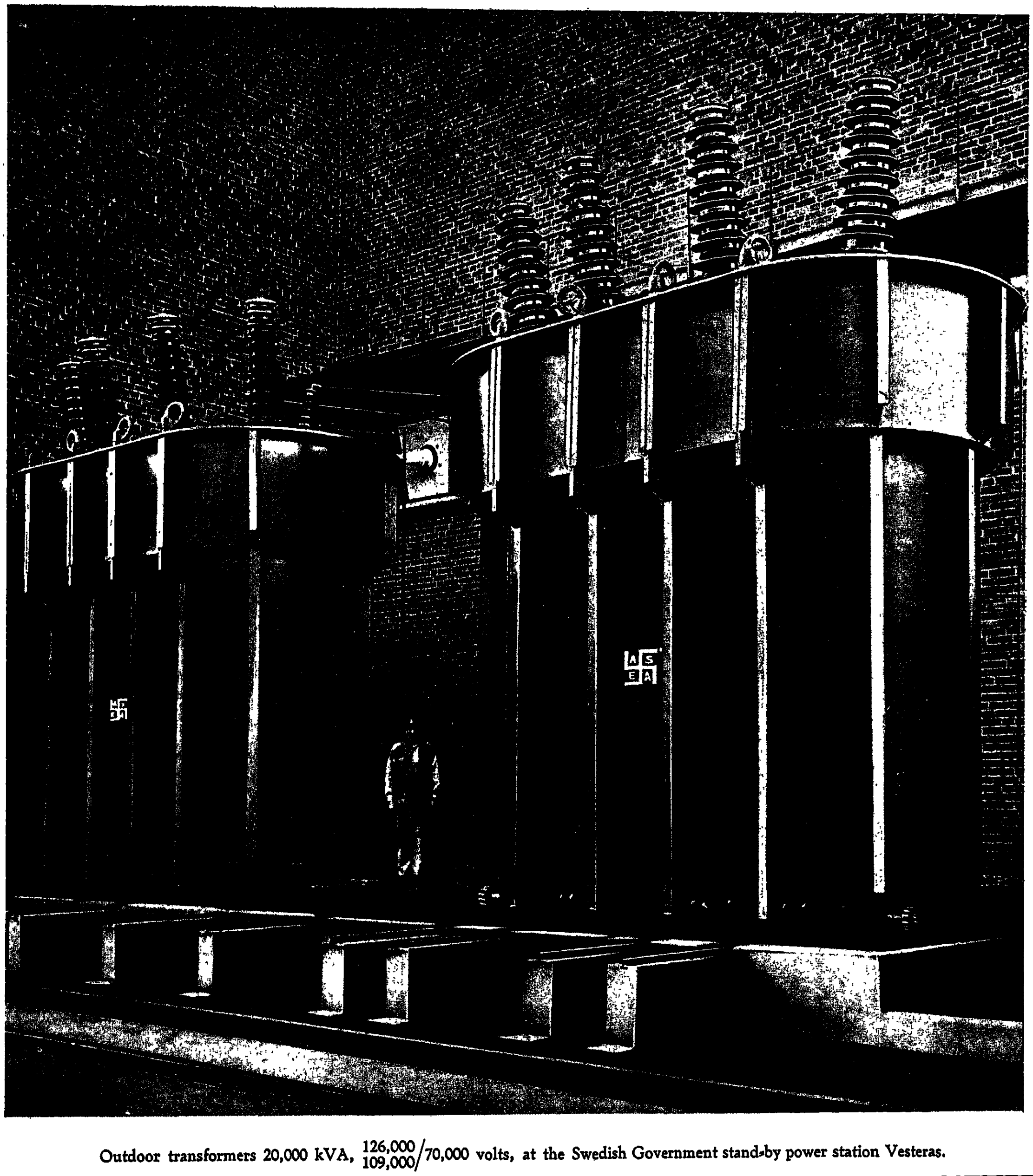
ALLMANNA SVENSKA
ELEKTRISKA A.B.
VESTERAS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

SEPTEMBER

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesteras, Sweden.

1924



Outdoor transformers 20,000 kVA, $\frac{126,000}{109,000}$/70,000 volts, at the Swedish Government stand-by power station Vesteras.

TRANSFORMERS TYPE TZ—EZ.

A review of the types of small transformers at present marketed by various firms reveals that development in different countries has proceeded along the lines of two particular arrangements. The types differ in general with respect to the arrangement of leading through bushings, cover, and tank. In the one arrangement, chiefly favoured by European firms, the terminals are placed in the cover and this is joined to the core making one mechanical whole. The insulators consist of copper bolts fixed in porcelain leading through bushings. In the other arrangement, used mainly by American firms, the terminals are placed on the side of the tank and are held in removable carriers made to receive them. The cover is entirely separate from all other parts and the core is usually stayed to the tank itself. The connections are taken up to a coupling board fixed above the transformer yoke. Commonly, insulated cables are brought out through the porcelain bushings.

In the construction of this last type it will be seen that the greatest attention is given to making the interior of the transformer as accessible as possible. The number of screws for holding down the cover is as small as possible, usually only two or four. As soon as these are loosened and the cover lifted the coupling board which lies immediately below can be got at to make alterations to the connections. This was, at any rate in earlier times, a great advantage. As transformers can now be built with self contained coupling arrangements which are operated from without, and with which no dismantling of the transformer is necessary, the above consideration disappears entirely. Regarding this question reference may be made to the article following in which arrangements for voltage regulation in transformers are further described.

Attention may be drawn to a disadvantage inherent in the American type. It follows from the placing of the leading through insulators that the distance between the high tension connections and the side of the tank is necessarily small, so that the type does not lend itself to high voltages. The case is made still more difficult by the fact that the bushings are fixed in place with compound, which is often not impervious to oil, and is not a satisfactory packing for warm transformer oil. The tank must accordingly not be filled up so that the oil comes above the bushings, and the parts of the insulators inside the transformer are accordingly in air. Under these conditions it is not possible to provide the transformer with an expansion vessel. It is also clear that there is danger, should there be a flash over between the inner parts of the insulators and the tanks, of an explosion of gas from the oil, and the air above the oil, occurring. The type should not be used for pressures above 11 kV. A point which is often urged with these types is that the cover is entirely free from holes, for screws and insulators, which makes for watertightness when placing the transformer out of doors. It must however be pointed out that there is no doubt that fully satisfactory packings can be made for such places, and there is too large a number of transformers of the European standard type in service for this construction to be condemned. On the contrary these packings are more satisfactory than those of the American type, since the former can be fitted on transformers with expansion vessels, without further alteration, and it will be realised that it is much more difficult to pack joints to withstand warm oil, under pressure, than to withstand water. With the latter type of transformer the number of screws for the cover is so small that the increased pressure due to an expansion vessel causes the oil to run out even if the cover joint is cemented. As a protection against the entrance of damp the cover is often arranged with deep overhanging edges which are found to prevent this very effectively.

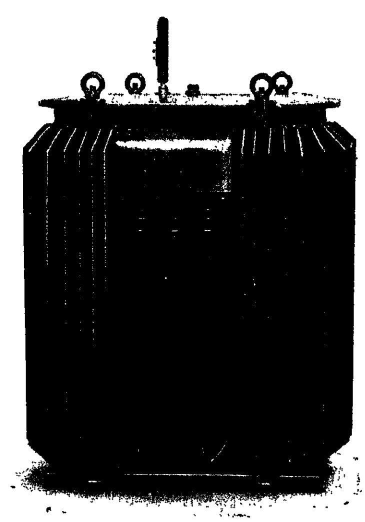


Fig. 1. Three phase Transformer Type TZ 2556/123, 75 kVA, 6,000 ± 5 %/220 volts, with base frame.

In order to meet the wishes of customers who prefer the American type, Asea has constructed a series of small three phase and single phase transformers embracing types TZ and EZ in sizes up to 150 and 100 kVA respectively. In these as far as possible, the experience gained with former transformers, and the points touched on above have been embodied. At the same time it was considered necessary to arrange the leading through bushings in such a way that the oil level comes above them and also over any current carrying parts within the transformer tank. To this end the in-

sulators are not cemented in with compound, but special insulator flanges are provided, against which the terminal insulators are clamped to the tank from without, by tightening specially threaded nuts. This affords the advantage that insulators can if necessary be very easily changed. The incoming cables end in the leading through bushings where they are soldered to massive bolts, which pass into the tank. The oil does not thus come into contact with the cables and creepage of the oil is eliminated.

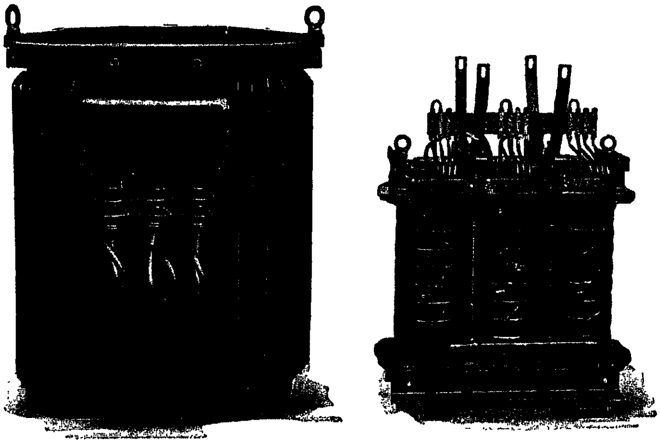


Fig. 2. Three phase Transformer Type TZ 1540/91, 25 kVA, $6{,}600^{+2.5}_{-5}\,\%/415$ volts, Y/Y connected, 50 cycles.

The insulators are of porcelain from 3000 volts upwards and are provided with from one, up to four petticoats, depending on the voltage. They are carried in boxes welded to the side of the tank. Great care is taken to make the cover damp proof, but to meet the wishes of customers only the minimum number of bolts necessary is used.

The covers for all types are of cast iron and are well domed so that no water can rest on them. The sides are flanged as far as possible over the sides of the tank to prevent water from reaching the packing between cover and tank. The cover is provided with a groove on the inside into which a massive rubber packing, having a section $1/2'' \times 1/2''$, is pressed. As this packing is particularly elastic a moderate tightening of the cover screws serves to make thorough contact between the cover and the angle iron at the top of the tank and a perfectly tight joint is obtained. The cover screws are furnished in the form of eye-bolts and when these are loosened they are free to fall sideways against the sides of the tank. This effects a great saving in time and trouble, while in addition all possibility of nuts and washers becoming lost is removed.

The four smaller types are arranged with two such screws and the two larger with four.

All transformers are furnished, unless otherwise ordered, with two extra tappings on the high tension winding, under the cover. These tappings are taken up to the coupling board fixed over the core and are accessible as soon as the transformer cover is lifted off. To make connection between these couplings as easy as possible the coupling board is made in a special way as shown in the accompanying figures. It consists of a bakelite panel to which gunmetal contact pieces are screwed. These contact pieces are furnished with plug holes and connection is established between them by U-shaped links by moving which transformers can be easily coupled as desired.

The general construction of the transformer is in accordance with the following description.

The core is made of cruciform section so that circular coils can be used. It is assembled from high permeability sheet iron, made in Asea's own works, with particularly good figures as regards losses and no appreciable ageing effect.

The windings are cylindrical in form, the high tension winding being in general placed outside the low tension winding.

A noticeable property of these transformers is that the coils are in general particularly broad in the radial direction, so that there are wide supporting areas between coils and also between the coils and the yokes. The insulation between the high and low tension windings, and between the low tension winding and the core, consists of bakelite cylinders, and channels are left between the two windings, which are dimensioned with regard to mechanical features as well as considerations of test pressure, being made fully large so that there are roomy oil passages between the above mentioned bakelite cylinders and the high and low tension windings. Moreover the high tension windings are divided up into a particularly large number of small coils, divided by oil passages, so that the cooling of the windings, and especially the high tension windings in which

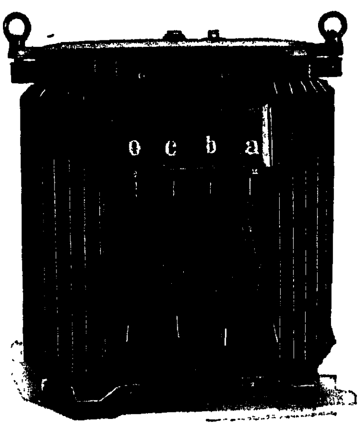


Fig. 3. Three phase Transformer Type TZ 2030/92, 20 kVA, $11{,}500^{+5}_{-10}\,\%/400$ volts, with brackets for pole mounting.

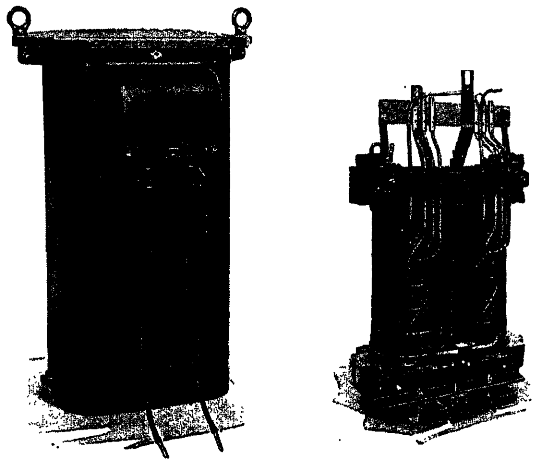


Fig. 4. Single phase Transformer Type EZ 1035/90, 10 kVA, $3{,}000\ {}^{-2.5}_{-5}\ \%/240$ volts, 50 cycles.

a greater temperature is commonly reached, is particularly effective, the oil in this case circulating round all four sides of the coils. This construction is a great advantage also in drying the transformer, as the moisture is naturally more easily driven out than it could be if the design were more compact and the windings placed close to one another, or to the insulating cylinders. Both high and low tension coils are subjected, before mounting in the transformer, to careful impregnation in a vacuum with oil resisting varnish, the composition of which is designed to afford mechanical stability to the coils and also to protect them from the absorbtion of moisture during transport.

All these transformers are contained in welded steel tanks. The tanks are plain for the smaller transformers and corrugated for the larger. Special care has been taken to make them mechanically strong. All the corrugated tanks are furnished with bottoms of thick plate and with specially deep flanged edges, so that the sides are protected when shifting the transformers with a crow-bar. The two larger types TZ 2500 and 3000 are provided with a separate base frame of wrought iron to further protect the tanks against deformation. The transformers are so constructed that they can be transported under the most adverse conditions without removing the cores from the tanks and to this end the core is very carefully stayed to the sides of the tank. The core is furnished with longitudinal and transverse braces on the upper and lower yokes of the core and these are adjusted in the shops when the core is placed in the tank, so that no internal movement either sideways or endways is possible. Separate from these braces are four heavy iron stays which reach from the upper yokes to the angle iron round the top of the tank. A test was made by dropping a transformer braced in this way and packed in the usual manner from a height of 2 metres on to a stone floor so that the transformer fell bottom upwards. This demonstrated that such treatment could be withstood without any damage whatever to either transformer or packing.

These transformers are dimensioned to withstand test pressures in accordance with the S.T.F. 1920 (Swedish Technical Society's Rules for standardisation of electrical apparatus), which considerably exceed those required by the British standards which are commonly specified when transformers are sold to customers outside Sweden.

The temperature rise as measured in the oil does not exceed the limits allowed by the British and American rules. Most of the types in the range show at the same time a considerably lower temperature rise on test from which it follows that they can withstand very heavy overloads without injury. Further particulars of these transformers will be given glady on request.

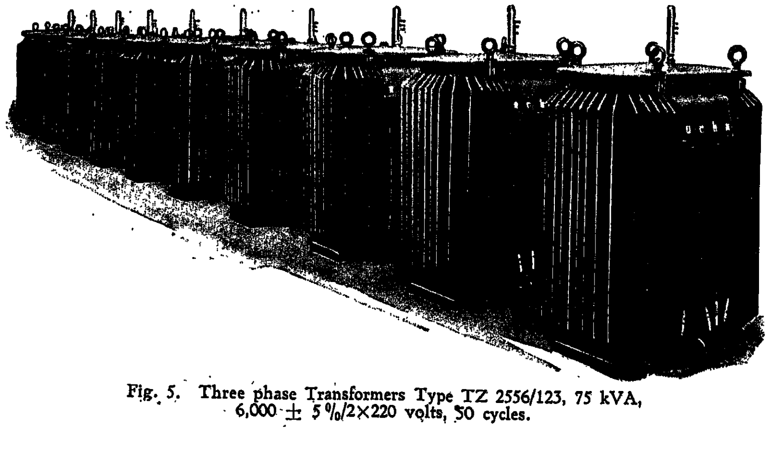


Fig. 5. Three phase Transformers Type TZ 2556/123, 75 kVA, $6{,}000 \pm 5\ \%/2 \times 220$ volts, 50 cycles.

DEVICES FOR VOLTAGE REGULATION ON TRANSFORMERS.

For a long time past it has been usual to provide transformers with regulating tappings on one or both windings and as the need for these has increased on account of the continual growth of power networks and loads, the question of a suitable arrangement for these details in transformers has lately advanced from a consideration of small importance to one of the greatest possible weight, often indeed becoming a determining factor in the construction of a transformer. During the last few years a great deal of work has been done in this direction and it may be useful to give a short description of the constructions which have been used, and to indicate the points which should be taken into consideration when determining their suitability for different conditions.

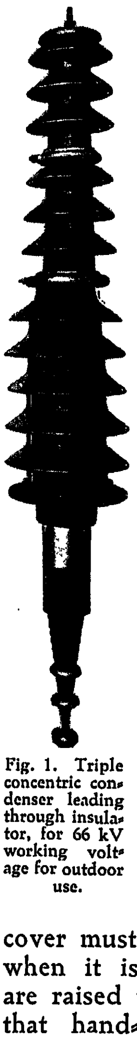


Fig. 1. Triple concentric condenser leading through insulator, for 66 kV working voltage for outdoor use.

Regulating tappings can be made accessible in several ways. The cheapest and simplest arrangement is to bring these tappings up to the upper yoke on which are mounted contacts or a coupling board. In most cases however this arrangement must be regarded as very unsuitable and this is particularly so when transformers have terminals mounted in the cover, which is the standard practice of most Swedish and European firms.

In order to make the connections accessible the cover must first be taken off, and as in general it is not possible to disconnect the winding from the terminals, it follows that the cover must be rigidly fixed to the core, so that when it is lifted the core and all connections are raised with it. It has often been suggested that hand-holes should be provided in the cover through which the connections could be reached. It may be remarked, in this connection, that as a three-phase transformer is commonly provided with 7 terminals it is not possible to reach all the connections with one hand-hole, although there is seldom sufficient room for more, and it is very unpleasant to have to work with the hands under the cover, so that it is not possible to see what is being done to say nothing of the risk of dropping nuts etc. into the tank. It must accordingly be considered necessary that in order to reconnect the winding the core and the cover must be lifted. This may be a very extensive undertaking. A transformer can for example be imagined which is supported on poles, or a large power transformer installed in a place where lifting tackle is wanting. As a general rule as such tappings seldom, if ever, require to be changed, there is good reason to discontinue the use of this construction. If transformers are arranged in accordance with American practice, with covers freely removable, the above remarks do not apply, and in this connection the foregoing article in this number on Asea's TZ—EZ types may be referred to. A suitable and simple arrangement of reconnection board for these types is shown in the figures (2 and 4 belonging to the article on TZ—EZ types).

Returning to transformers with the terminals placed in the cover it was soon evident that the primitive method of placing the tappings under the cover would have to be improved and for this reason transformers have been built for a long time with tappings brought out through the cover and provided with additional terminals by means of which reconnection can be effected from without. For small trans-

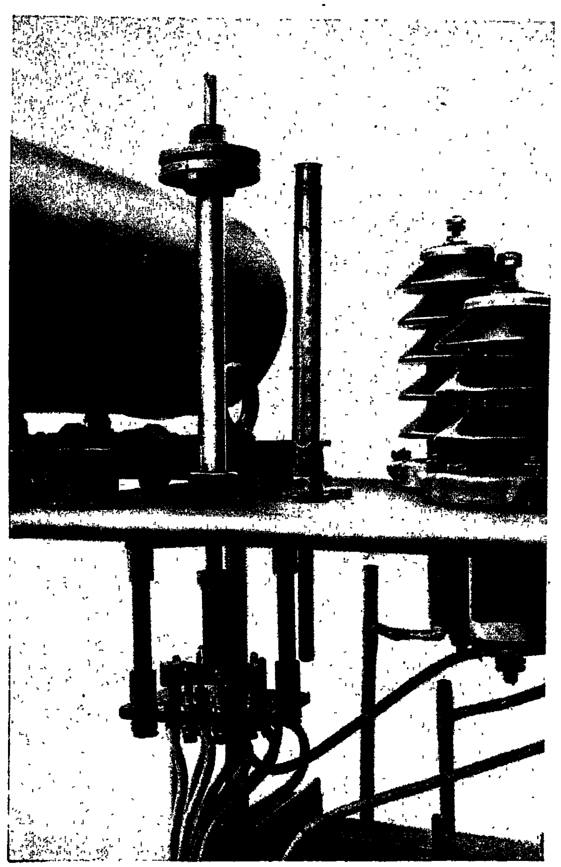


Fig. 2. Neutral point re-connecter.

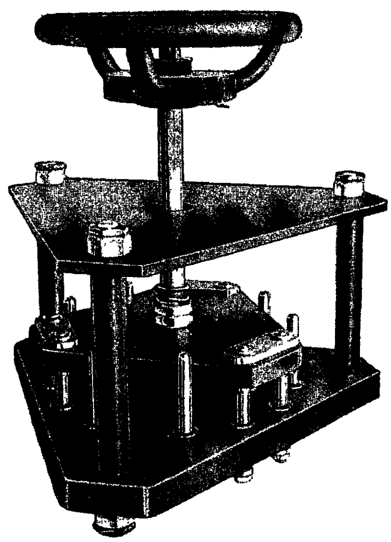


Fig. 3. Re-connecting device for re-connecting in the centre of the winding.

formers however, and also for large transformers where the working pressure is high, the space on the cover for such extra terminals is very restricted and it was necessary to construct terminals of a special kind so that several tappings could be brought out through the same insulating bush. After several variations in the construction, these terminals are now made, in general, with a central leading through bolt and one or more concentric copper tubes insulated from the bolt and from one another, to which tappings, for voltages which do not differ by a great amount, are connected.

That the introduction of these insulators represents an improvement is obvious, but the arrangement can by no means be regarded as ideal. The chief drawback is the cost. In order that the concentric type of terminal may work without giving trouble the construction must be very carefully carried out.

As an example it may be mentioned that for higher voltages Asea found it necessary to make

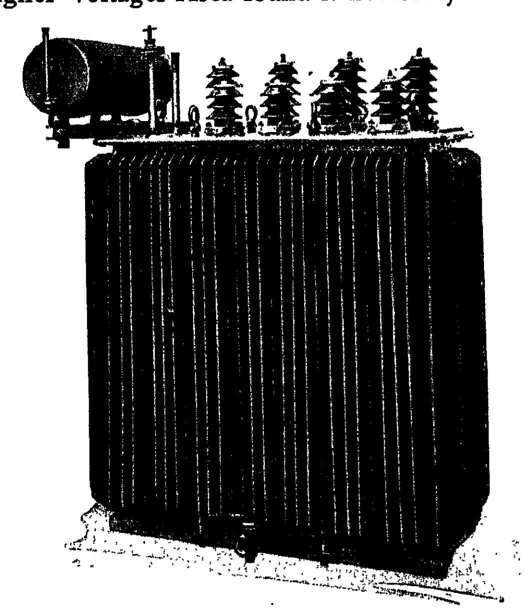


Fig. 4. Transformer with neutral point re-connecter.

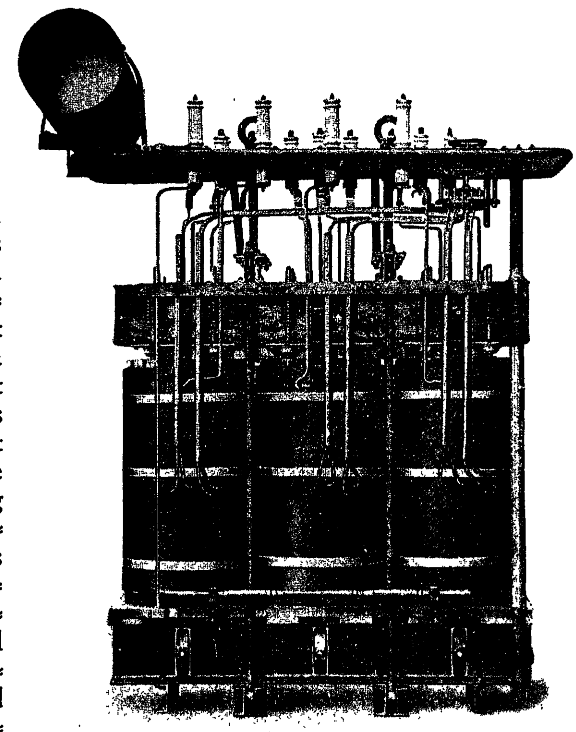


Fig. 5. 1,600 kVA three phase transformer with self contained re-connecter.

the insulating linings between the central bolt and the tubes as separate condenser concentric bushings. To protect the insulators against the wet both the main bushings and the separate parts of the insulators are protected by porcelain mantles and the space between the porcelain and the bakelite bodies filled up with compound. This construction is used both for indoor and outdoor insulators and is at present furnished with three terminals, as a maximum, and for pressures up to 88 kV. Fig. 1 is an example of such an insulator designed for a working pressure of 66 kV. It is obvious that the cost of this arrangement must be very high and this disadvantage is increased by the fact that it is desirable for the extra tappings not to be at the main terminals, but at the neutral point, or from the central part of the winding, in which case the voltage difference between them and the main terminals requires the provision of one or more sets of separate terminals for reconnection. Further it may be remarked, against the arrangement as a whole, that incorrect coupling up is in no way guarded against.

These disadvantages can be overcome if the transformers are furnished with self contained apparatus to which the tappings are brought and which is fitted with an operating device placed outside the tank, so that the transformer can be reconnected for different voltages without

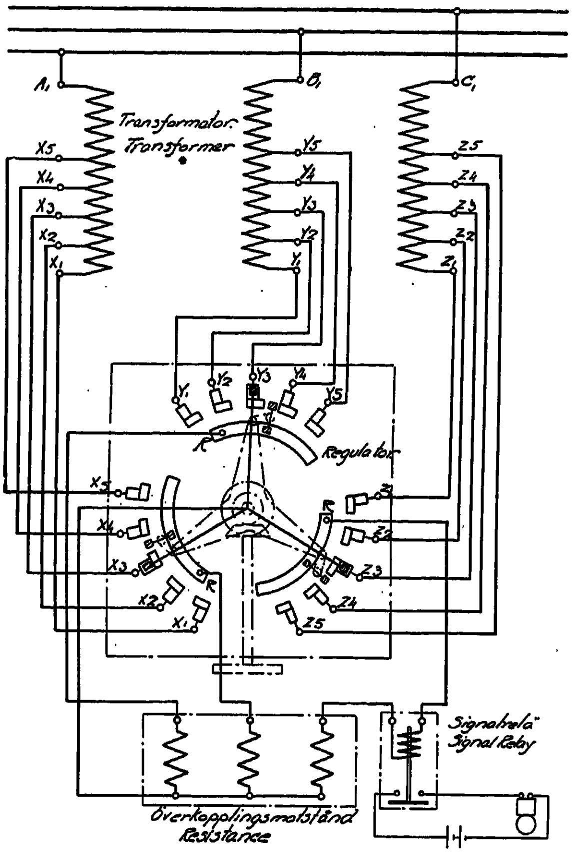


Fig. 6. Diagram of winding coupler and transformer.

the necessity arising to dismantle it in any way, or to loosen any connections. The reconnection is carried out with the transformer disconnected from the supply.

Such devices have been constructed by several leading firms, but none of them, so far as is known, fulfil all the requirements for such an apparatus which are given below. For such fittings the following points are considered by Asea to be desirable:

1. It must be impossible to make mistakes in reconnecting the transformer.

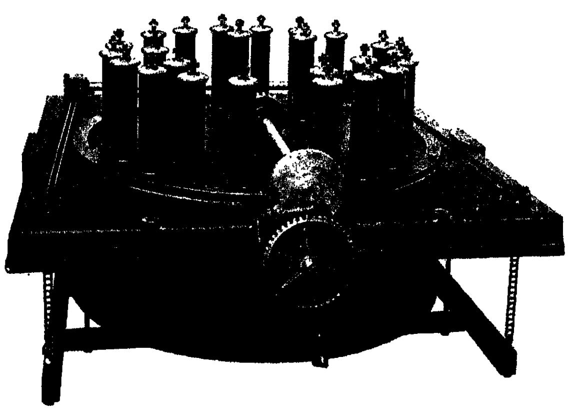


Fig. 7. Winding coupler with 6 steps, 22 kV, 200 amps, exterior view.

2. The various positions must be clearly marked.

3. It must be impossible to leave the device in any neutral position.

4. The contacts must be capable of carrying the maximum short circuit current which can occur.

5. The insulation must be satisfactory.

Asea's apparatus which fulfils all the above is made in two different patterns, namely for connecting in the neutral of Y or Z connected windings, fig. 2 (neutral point coupler) and for reconnecting the centre points of windings (in delta connected windings), fig. 3.

Point 1 above is partly ensured by the fact that the transformer is not furnished with three separate single phase couplers, but the arrangement is common to all phases and they cannot accordingly be connected for different voltages. The series of connecting devices introduced by Asea, covering, at present, patterns for pressures up to 44 kV, is constructed, for this reason, of the three phase type with a connecting device for simultaneously coupling the three phases. The neutral point coupler consists of a number of precision machined contact pins fixed in a common insulating block of special non-hygroscopic material. The material of this block is homogeneous and exhibits no stratification in the longitudinal direction. A triple contact arm which has three contacts for the different phases simultaneously completes the neutral point. The contact arm is of course insulated from the operating spindle. Above the cover the operating spindle is fitted with a handle fixed to a disc furnished with holes corresponding in number and position with the desired positions of the contact arm. By the introduction of guide pins corresponding to the holes a perfectly exact correspondence is obtained above the cover with the arrangement of contacts beneath. The guiding pins are threaded and provided with nuts

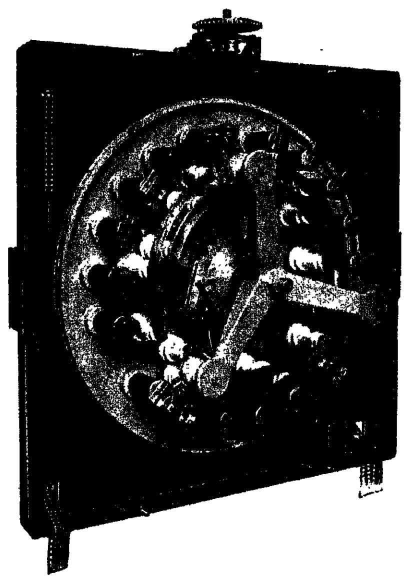


Fig. 8. Winding coupler with 6 steps, 22 kV, 200 amps, interior view.

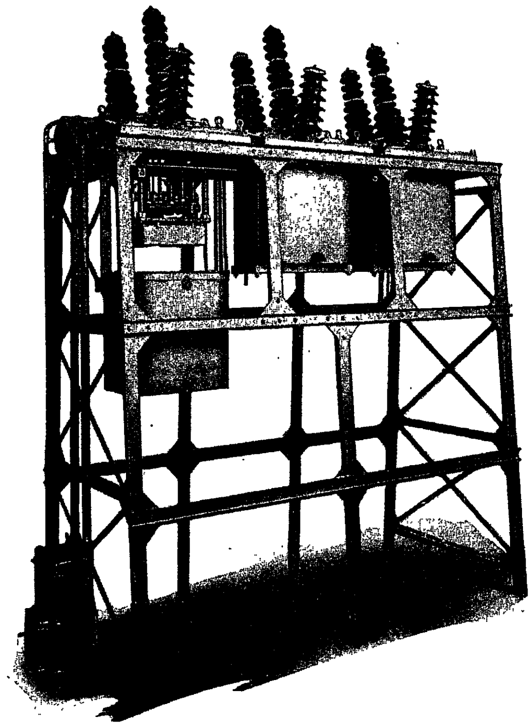


Fig. 9. Winding coupler for 6,000 kVA three phase transformer, for outdoor erection.

by which the device can be locked while at the same time the spindle packing is compressed making the gland oiltight. When reconnecting, the nuts are removed after which the operating spindle has to be drawn vertically upwards. As the guiding pins are longer than the contact pins the operating handle cannot be turned before the contact arm is free of the pins. When the arm is turned it is quite impossible to lower the operating spindle again until the guide pins are opposite to the next holes in the guiding disc. The positions of the operating handle could not be better determined. Contact is broken altogether in the neutral position.

With regard to insulation these devices have been designed to meet the following requirements: the flash over voltage between neighbouring pins is at least equal to the working voltage, the flash over voltage to earth is made the same as the flash over voltage of the terminal bushings. In three phase couplers for making reconnection at the centre of the windings the flash over voltage between the contact pins belonging to different phases is at least equal to the test pressure for the winding.

In order to demonstrate the manner in which the apparatus will stand up to overloads some particulars are given from test results obtained with a neutral point coupler designed for a normal current not exceeding 60 amps. The temperature rise was determined with the apparatus immersed in oil by means of a thermo-element arranged close to the contact. It was found that the temperature rise at the contact pin was lower than the temperature rise at the nuts of the connections, namely 2.5° as against 3.8° with the normal current. The temperature rise was further determined at the contact pin after a varying number of reconnections between two positions with the following results:

At commencement of test	2.4°
After 1,000 reconnections	2.2°
After 3,000 reconnections	2.1°
After 20,000 reconnections.........	2.0°

The contact accordingly improves with use.

The following load tests were carried out:

A current of 500 amps was passed from one contact pin, through the contact arm, to another pin, for 5 seconds. When the apparatus had cooled a current of 1,000 amps was similarly passed for 5 seconds and the apparatus again allowed to cool. In the same way the current was increased 500 amps each time for periods of 5 seconds. After each period of load the contacts were examined for signs of burning. After a load of 3,500 amps no signs were visible but when the current reached 4,000 amps the centres of the contact pins were found to be burnt to the contacts. This indicated that the

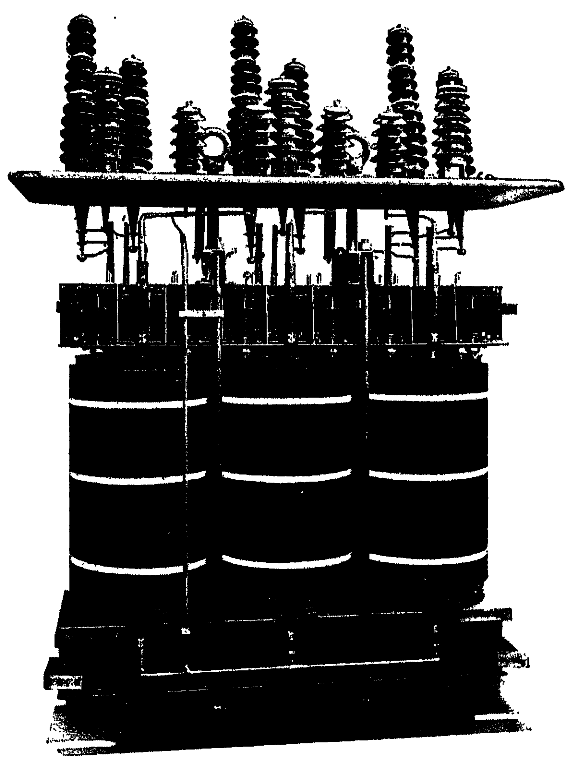


Fig. 10. 6,000 kVA three phase transformer, 46,000/61,000, 58,000, 55,000, 52,000, 49,000 volts, 50 cycles, for outdoor erection, low tension side.

melting began from the inside of the contact as there were no signs of it where good cooling was possible.

The apparatus is made for voltages up to a maximum of 44 kV for both star and delta connected windings, normally with three, and with a maximum of five, positions.

The apparatus which has just been described certainly meets most demands for a tapping changing arrangement, but it should be noted that it must only be operated when there is no pressure on the transformer. Most transformers can, without inconvenience, be taken out of service for a few minutes during some part of the day or night. When this is not so, or in cases where it is desirable to follow the voltage variations on a network continuously, the method is less suitable. In such cases the transformers must be arranged for voltage variation on load. They are then fitted with tappings brought out through the cover for each voltage, the concentric type insulators already described being made use of. For making changes to the different tappings Asea manufactures a special apparatus known as a winding coupler. This is installed separately, and is built on the same principle as an ordinary cell regulator. Fig. 6 is an example of a diagram of connections for such a regulator arranged for giving 4 voltage variations by altering the neutral point connections of a star-connected transformer winding. It may be remarked, in parenthesis, that for the lower voltages it is sometimes possible to assemble the transformer and winding coupler together by which means a saving in the space required for installation is effected. From the erection point of view this is also an advantage as the cables between the transformer and the regulator are done away with.

The apparatus is as shown in figs 7 and 8 and it will be seen from these, and the diagram, that the contacts are arranged in a circle over which a contact arm, making the neutral point connection, is movable. This arm is shifted over the 5 contact positions by a toothed wheel with an operating sprocket wheel so arranged that the contact arm is moved one complete step for each turn given to the operating sprocket. During transition from one position to another a resistance is first connected between the respective contacts so that the short circuit current in the section of transformer winding lying between them is limited to a value which causes no dangerous heating. During the movement of the arm the load current is never broken; for an instant it passes through the resistance, which however is short circuited as soon as the new contact is reached.

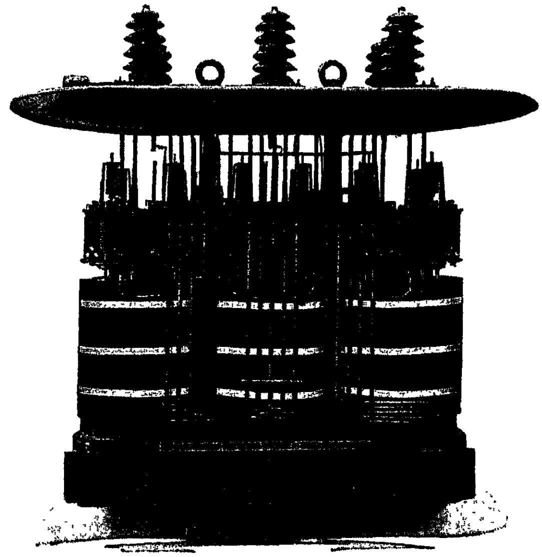


Fig. 11. Three phase transformer type TVOS, 3,000 kVA, 42,000, 41,000, 40,000, 39,000, 38,000, 37,000/37,000, 36,000 volts, 50 cycles.

The mechanism is immersed in oil and the oil container can be lowered for inspection of the contacts. Current is taken to the apparatus through single or multi-concentric terminals of the same type as are used on the transformer. The arrangement can be made for hand or electric operation, in the last case by means of push buttons or automatically by a contact voltmeter. These arrangements have been made for a considerable time for regulating the voltage for operating electric furnaces. Lately the interest of a large circle of customers in these has greatly increased and Asea now builds apparatus for voltages up to, and including 66 kV. For these high voltages the construction just described has been departed from on account of difficulties in insulating. Sliding contacts have been replaced by a number of contactors operated by a cam shaft placed just below the cover. The cams are arranged so that the connections before described are effected in proper order. Fig. 9 shows such a winding coupler for 66 kV arranged for 5 steps. The apparatus, which is built for out-door use is operated by a motor contained in a water tight cast iron housing seen in the lower left hand corner of the figure. The winding coupler is carried on an iron framework of such a height that the connections between the transformer and regulator are as simple as possible. To this end also the terminals on the transformer and regulator are arranged opposite to one another in a reflex manner. The connecting leads accordingly run across from one to the other, horizontally, and parallel to each other.

The following may be referred to from recent orders:

60,000
58,000
TOS 78 — 6,000 kVA — 42,000/56,000 — Y—0/Y—0 — 50 cycl.
54,000
52,000

61,000
58,000
TOS 78 — 6,000 kVA — 46,000/55,000 — Y—0/Y—0 — 50 cycl.
52,000
49,000

60,000
58,000
TVO 68 — 5,000 kVA — 5,500/55,000 — Y—0/Y—0 — 50 cycl.
53,000
50,000

40,500
39,000
TO 68 — 4,000 kVA — 37,000/3,000 — Y—0/D — 50 cycl.
36,000
34,500

39,200
37,750
TO 57 — 2,000 kVA — 36,300/3,050 — Y/Y—0 — 50 cycl.
35,350
33,950
32,550

As the voltage regulation problem is in these days a very real one, it is hoped that the constructions dealt with above will receive the careful attention of our readers, since they provide an effective and, in comparison with other methods (e. g. the induction regulator), a cheap solution of the difficulty.

THE COOLING OF TRANSFORMERS.

The designer encounters the problem of efficient cooling in all branches of electric machine manufacture, but it could hardly be of more vital importance than in transformer work, since the temperature rise in the different parts of a transformer absolutely determines the load which it will carry, and this is not the case with other electrical machines. This problem has been handled from many standpoints in a number of publications, so that it is not intended to touch here on the theoretical side of the question, although there is still a great deal to be added, but to give a short account of the characteristics of the different methods of cooling drawn from results obtained with some modern and well tested Asea designs, and some cost comparisons based on to-days prices of materials.

Air cooling is the oldest method in use, but in these days the customer and transformer manufacturer are agreed that it is no longer suitable.

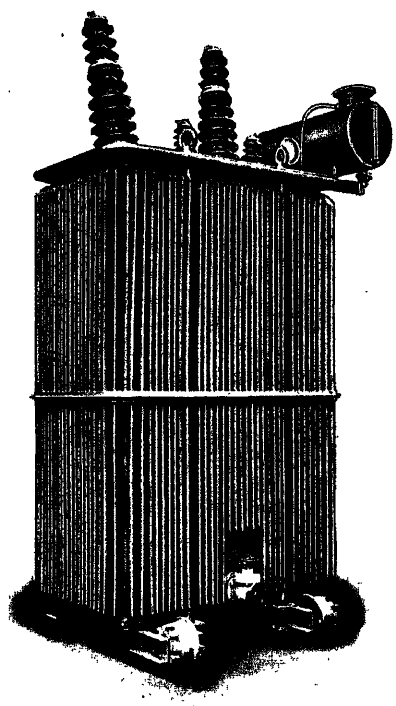


Fig. 1. Single-phase transformer type EOS 57, 750 kVA, $66{,}000-{}^{2.5\%}_{5.0\%}/6{,}640$ volts.

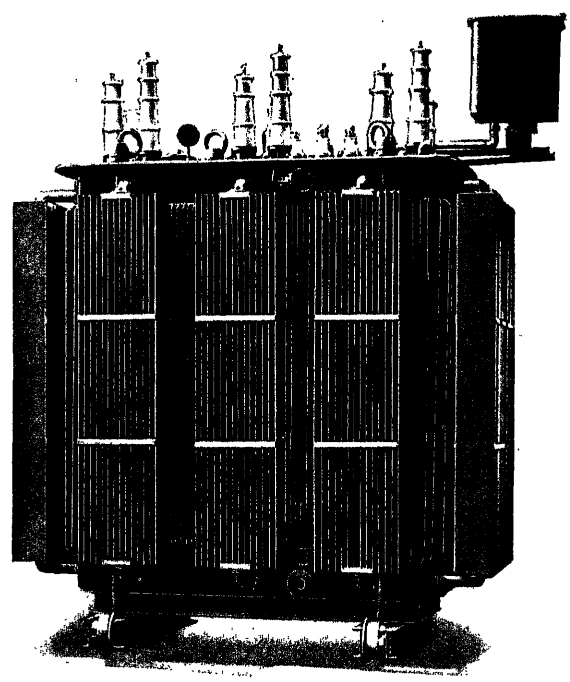


Fig. 2. Transformer with corrugated tank and cooling pockets, 4,000 kVA, 40,500/3,000 volts.

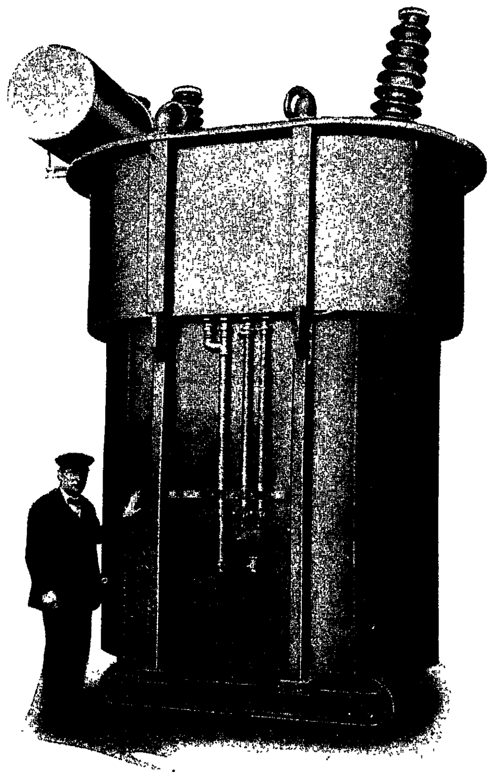


Fig. 3. Single phase transformer type EVO, 3,000 kVA, 57,700—2.5, 5, 7.5, 10 %/12,000 volts.

The reason for this is the unsatisfactory service given by these transformers arising from the fact that in order to allow the air free access to the windings no adequate protection against mechanical damage can be provided. Such transformers also are very sensitive to overloads which can only be allowed to persist for a comparatively short time. This follows from the fact that in general the windings can, with regard to heating up, be considered as isolated bodies which without intervention of other materials give up the heat generated in them straight to the cooling medium. Their behaviour can be made clear most easily by means of an example. Consider a transformer, which on full load has a temperature rise, as allowed by the S.T.F. Rules, of 60° C in the windings. Then with a 50 % overload a temperature rise of $1.5^2 \times 60 = 135°$ C is obtained in the windings. It is to be noted that this temperature is reached after a relatively short time, — about 30 minutes — as a result of the low heat capacity of the windings. This is quite otherwise in an oil cooled transformer. In the latter type the increased temperature of the windings can be considered as divided into two intervals, first the temperature difference between the air and the oil, and secondly the temperature difference between the oil and the windings. For a temperature rise, as allowed by the S.T.F. and with an ordinary standard transformer construction, the values assigned to these may be 45° and 15° C respectively. When an overload occurs these two temperature increases vary in an altogether different manner, for the first, at any rate for short overloads, remains practically constant on account of the large heat capacity of the oil while the second follows the load variations immediately. In the case of the example considered above the temperature reached with an overload of 50 % of short duration is accordingly $45 + 1.5^2 \times 15 = 79°$ C in the windings. This shows that the same overload which would entirely destroy an air cooled transformer leaves an oil cooled transformer practically undisturbed.

Asea on this account has practically abandoned the air cooled type which is only built in sizes up to 10 kVA and for voltages up to 3,000 volts, and from the above considerations this limitation is only to the customer's advantage. Even from the point of view of first cost air cooled transformers are at a disadvantage in sizes above 10 kVA.

Self cooling oil immersed transformers. This method of cooling can be considered without doubt the ideal one. All the disadvantages referred to above are removed. The windings are protected against every kind of damage; the overload capacity is large (see above) and such transformers can be left entirely without attention, especially where, as in the case of Asea's transformers, indicating and contact thermometers are fitted. On account of the superiority of this method of cooling most of the transformers furnished by Asea are made

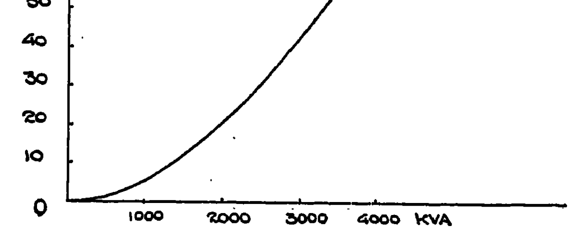


Fig. 4. Relation between the price of self-cooled oil immersed transformers and water cooled transformers.

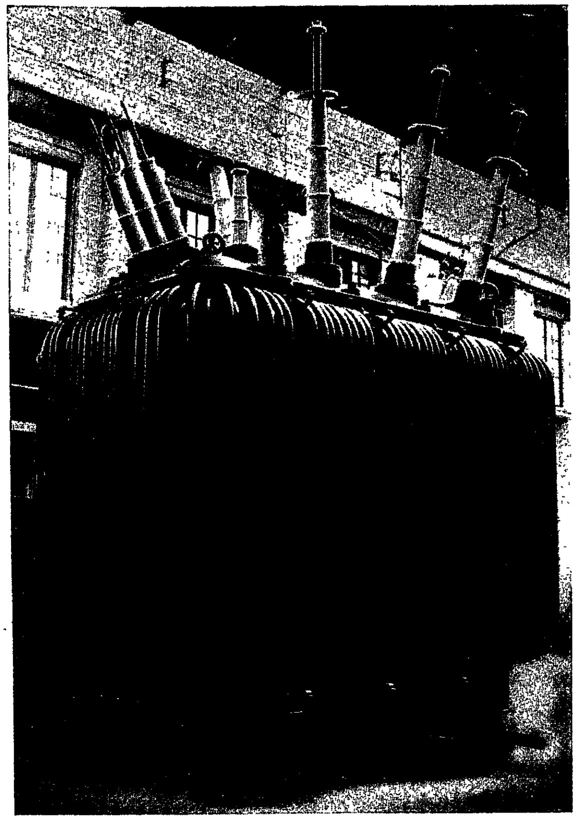


Fig. 5. Forced air cooled transformer with cover-plates removed. 4,000 kVA, $\frac{72{,}500}{67{,}500} / \frac{77{,}500}{70{,}000} / \frac{23{,}000}{20{,}000}$ volts, 50 cycles.

in this way. Unfortunately however the usefulness of the method is limited in larger units on account of the fact that as the output increases the amount of cooling surface does not increase in the same propertion as the heat produced in the transformer. Asea's standard series of transformers are designed with full consideration to the above.

The smallest oil cooled transformers are provided with tanks having plain sides of flat plate, while for an output of about 30 kVA the tanks are made of corrugated sheet. The corrugations become deeper and deeper with increasing output until at about 1,500 kVA the economic limit is reached for this construction. In order to make this excellent method of cooling suitable for larger units Asea has introduced a further construction which is shown in fig. 2. The transformer tank consists of an ordinary plain sheet steel tank, but a number of corrugated cooling pockets are welded to it through which the oil circulates, and by this means the greatest possible cooling surface is obtained within a relatively small space while at the same time the quantity of oil required is reduced to a minimum. Asea has lately introduced designs in which these pockets are made easily accessible for cleaning. The tanks are welded throughout and are a very good example of Asea workmanship. A further sample of Asea's self cooled construction is shown in fig. 1. This transformer is for 750 kVA, $66{,}000 - \frac{2.5\,\%}{5.0\,\%} / 6{,}640$ volts, and is arranged for outdoor mounting.

For the reasons given above there is a limit also to the use of this last construction. This limit is of a wholly economic nature and in this connection it is interesting to take note of the curve, fig. 4, which is based on present material prices and shows the approximate difference in cost between self cooled and *water cooled oil immersed transformers* in which cooling is effected by coils of water-tubes immersed in the oil. This method of cooling is usual for large units and can be used with advantage for sizes of 800 kVA and above. There is no upper limit. The principal advantage of this method, namely its low cost is clear from the above and to this of course is attributable the wide use which has been made of these transformers. Asea has accordingly given special attention to the construction of such transformers and all imaginable care is taken with their design. The cooling spirals are always made of solid drawn copper tubes which are subjected to severe tests before use. The transformers are provided with contact thermometers and signal devices, even if these are not specified by the customers, so that any interruption in the flow of the cooling water is immediately made evident. Asea has also developed a special design of tank in which the upper part is built out, as shown in fig. 3, affording a particularly well protected space for the cooling coils, and increasing the space available on the cover, so that a good spacing is possible between the terminals. This construction also makes possible a not inconsiderable saving in the quantity of oil required and a reduction in the overall height of the transformer.

At the same time water cooled transformers possess some disavantages which may be pointed out. A requirement for their use is for example a supply, free of charge, of cooling water which is as far as possible pure. Experience has shown that the working of these transformers is jeopardised by careless use. It has happened that customers have allowed water to remain in the cooling tubes during cessations of work in winter and the temperature of the transformer house having fallen to bellow 0° C the tubes have burst. In these cases when the transformers have been set to work again water has entered the oil and naturally caused a breakdown.

The above drawbacks are entirely overcome by the use of *forced air cooled oil immersed transformers.* It is surprising that this method of cooling has only been used so far to a comparatively small extent. Since such pioneers as the Swedish Waterfalls Board, the Swedish State Railways and the Hemsjö Power Company have ordered transformers of this kind it is to be hoped that they will come into more general use. These transformers have all the good points of the water cooled type with none of the disadvantages. They can be erected anywhere, being independent of cooling water, even in badly ventilated situations, since a fan provides the necessary cooling air. The safety of operation is very high following the displacement of the cooling water coils. As regards cost they do not necessitate any price increase and water cooled and forced air cooled transformers can be considered about equal in this respect. Lastly it may be said that this arrangement lends itself very well to the construction of large units for outdoor mounting. Asea builds these transformers in a similar manner to the self cooled transformers with the difference that the cooling elements are closed in by cover plates. Thus the method involves the use of well tried constructions only, and the fear of faulty operation on account of the failure of any new developments is quite absent. The cooling air is blown in through a duct leading to the centre of the bottom of the transformer and thence passes between the cover plates and the cooling corrugations of the ordinary tank construction. Besides the above Asea has introduced another construction suitable for conditions where the transformer can be expected to be subjected to great mechanical stresses and this construction meets most nearly the requirements of electric railway work. These transformers consist of a common plain tank made of thick welded wrought iron plates, but the tank is traversed by a system of vertical solid drawn steel tubes through which the cooling air passes and round which the oil circulates.

Transformers cooled by oil circulation. This arrangement is only used for very large units on account of the complicated nature of the auxiliary apparatus. They are accordingly to be regarded as quite special constructions and space will not allow of any full description of them. The foregoing has however made it clear that no case can be imagined in which equal advantages are not obtainable by the use of forced air cooling and this method can be recommended at all times, as the necessary apparatus is thereby to a great degree simplified and cheapened.

THE SAFE OPERATION OF OIL IMMERSED TRANSFORMERS.

Transformers occupy, with regard to the everyday stresses occurring in use, a particularly unfavourable position among the machines and apparatus constituting an electrical installation. Within a relatively small compass are collected a mass of turns of winding between which, on short circuit, enormous stresses arise due to electromagnetic forces. As all parts of a transformer are static the heat developed in the winding is only transmitted with difficulty to the surroundings or cooling medium. Between the different parts of the transformer, divided by relatively thin layers of insulating material, potential differences as great as 10,000 volts per cm or more can exist normally, while during disturbances, caused for example by an overhead line connected to the transformer, and of atmospheric origin, they can reach several times this value. A consequence of this is that a transformer, to be safe in use, must be constructed with the greatest care, so as to be able to stand up to the various stresses considered, which occur in normal operation. A number of considerations follow affecting the construction of transformers, which are carefully applied in the design of Asea transformers and which all tend to increase the safety of operation.

The windings of a transformer should be effectively cooled. This condition is partly met by using thin coils and windings in which the heat formed has only a short way to travel from the interior of the winding to the cooling medium. By the use of thin coils also, the maximum temperature reached is more easily calculated and kept to in practice, while the formation of hot spots in the winding can be prevented.

Fig. 1 shows an example of a transformer high tension winding divided to a considerable degree. The different coils are divided by oil channels which besides assisting the cooling give a high factor of safety against breakdown by flash-over between coils.

The coils and windings should be efficiently supported and must be of such shape that the mechanical forces arising from short circuits can be withstood without deformation. This may perhaps be best secured by using a transformer of so called shell type, which is used by Asea in cases where frequently occurring short circuits

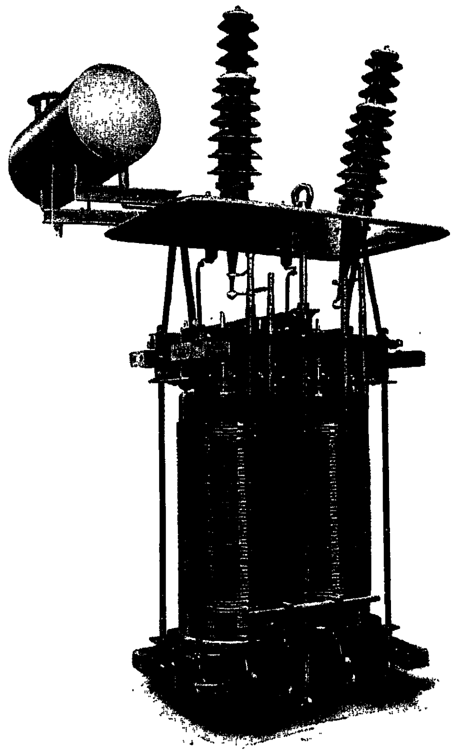


Fig. 1. Transformer with high tension winding divided to a considerable degree.

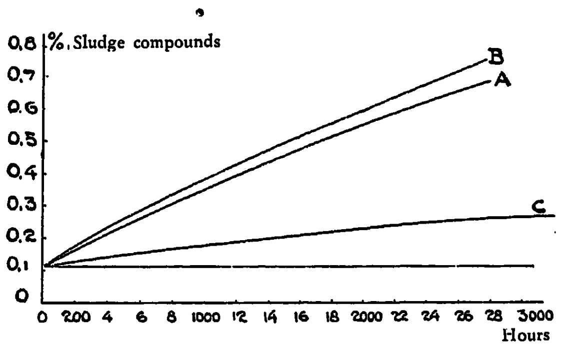
are to be expected. In core type transformers coils of cylindrical form are used as this shape most easily resists the radial stresses which chiefly occur with this type. The coils are constructed so as to obtain the greatest possible mechanical stability. When wire of small diameter is used the coils are impregnated with a binding and insulating compound which cements the separate turns together to a compact whole. All core transformers over some hundred kVA in size are provided with devices for tightening up the windings, as after a time these "settle" due to the influence of the oil and without some such provision the coils would shift due to the action of electromagnetic forces to an extent sufficient to endanger the connections and insulation. By making use of strong springs these tightening devices are made to work automatically.

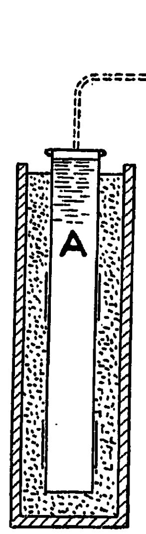
The insulation should be so distributed that extra high local electric stresses are avoided. Such concentrations have in general no time to manifest themselves during the ordinary pressure test, but after some time in use they lead to flash over and interruption of service. The insulation should further be of a material which has a small coefficient of expansion and care must be taken to see that the heat produced by the dielectric losses in the insulating material itself can easily be conducted away. By theoretical calculations and experiments with samples, the electric strains in the various materials have been determined with certainty. All dependence upon solid insulating material is avoided, and the insulation is principally provided by oil channels and relatively thin sheets of solid material. Oil has the characteristic that between 0—100° C its resistance to electrical breakdown remains practically constant and when used in thin layers it can compete with most solid insulating materials in this respect.

The character of the oil used is of particular importance to the safety of operation. By systematic research Asea has obtained all data regarding the most common oils on the market and makes use only of those of absolutely first quality. All oils which are used for cooling and insulating purposes in transformers undergo changes after being in use for a longer or shorter period due to the influence of the oxygen in the air. Resinous or tarry compounds are produced in the oil and are deposited upon the windings impeding or preventing the cooling. In an oil of good quality the changes take place so slowly and to such a small extent that no danger to operation is to be feared.

Fig. 2 is a drastic example of the result of using an oil of inferior quality. The photograph shows a transformer which is not of Asea's manufacture, just as it was removed from its tank. On examination it was found that the insulation of the windings under the layer of pitch was burnt. Another example of the condition of an oil after a relatively short time in use is shown in fig. 4. Lumps of pitch were found after a relatively short time in use, the transformer having been filled with an oil of inferior quality, in

Fig. 2. Sludging in a transformer.





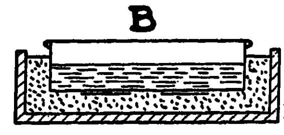
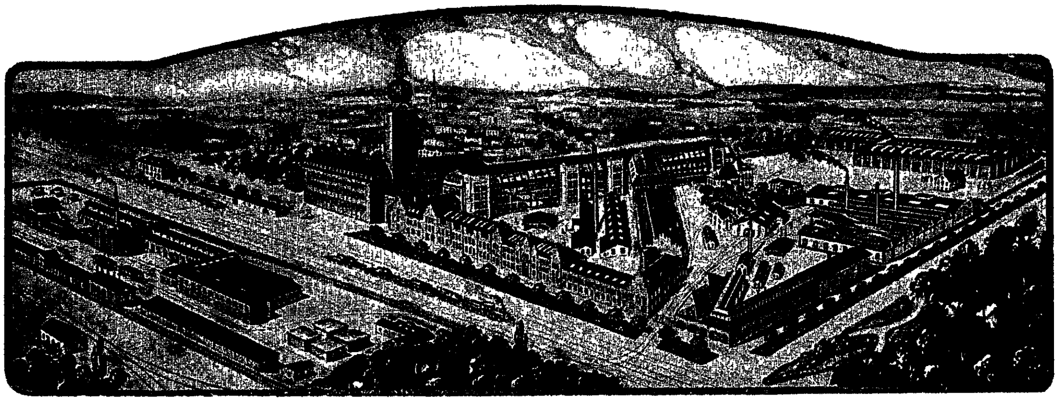


Fig. 3. Some experiments on sludging.

spite of the fact that a quantity of first class oil remained in the transformer when it was filled up.

A good preventative of sludge formation of this nature is, above all, the use of an oil of absolutely first class quality. Another is the fitting of an expansion vessel to the transformer so that air is excluded from it and only has access to the relatively small oil surface in the expansion vessel. It is of importance that the connection between the expansion vessel and the transformer is so arranged that warm oil is not able to circulate through the expansion vessel. The formation of sludge not only depends upon the area of the exposed surface of the oil, but also to a high degree upon the temperature of the oil which is in contact with the air. The curves in fig. 3 show the results obtained from some tests on sludge formation. Curves A and B represent tests with vessels A—B, in which oil was in direct contact with the air. The temperature of the oil was 100°. The tar compounds formed were isolated chemically. Curve C shows the result of furnishing container A with a small expansion vessel C, in which the temperature did not exceed 25°. The test clearly shows the advantage gained by the use of a correctly arranged expansion vessel.



Asea's head office and works in Vesteras, Sweden.

ALLMANNA SVENSKA ELEKTRISKA A.B.

Head office: VESTERAS, SWEDEN
Works: Vesteras and Ludvika
Telegrams: Asea, Vesteras

SWEDISH GENERAL ELECTRIC LTD

5, CHANCERY LANE, LONDON
Works: Fulbourne Rd., Walthamstow
Telegrams: Autosyncro, Fleet, London

OFFICES, ASSOCIATED COMPANIES AND AGENTS:

ARGENTINA
Compañia Sudamericana SKF, Buenos Aires. Victoria 502.

AUSTRALIA
Unbehaun & Johnstone, Ltd., Perth, W. A. 383/387 Murray Street.
Unbehaun & Johnstone, Ltd., Adelaide, 100 Currie Street.
Thomas Bros. Pty, Ltd., Melbourne. 201/203 William Street.
Australectric, Ltd., Sydney, Wireless House, 97 Clarence Street.
Intercolonial Boring Co. Ltd., Brisbane, 450/460 Ann Street.

BELGIUM
Société Belge d'Electricité Asea, Bruxelles, 21 Rue Grétry.

BOLIVIA
Graham, Rowe & Co., Oruro, Alianza 581.

BRAZIL
Haupt & Co., Rio de Janeiro, Rua São Pedro 50
São Paulo, Rua Boa Vista 46.
Porto Alegre, Rua 15 de Novembre 16.

CANADA
Swedish General Electric Ltd., Toronto, Ont., 107 Duke Street.

CHILE
Graham, Rowe & Co., Valparaiso, Cochrane 825.
Santiago, Bandera 267—275.
Antofagasta, San Martin 362.

CHINA
Henry J. Moysey, Shanghai, Peking Road 64.
J. Whittall & Company Ltd, Tientsin. 15 Victoria Terrace.

DENMARK
Elektricitets Aktieselskabet Asea, Copenhagen K, Bredgade 45.

ESTHONIA
Linke, Martinson & Co., Reval, Kinga tän 10.

FINLAND
Allmänna Elektriska Aktiebolaget i Finland. Helsingfors, Citypassagen.

FRANCE
Société Française d'Electricité Asea, Paris. Boulevard Haussmann 114.

HOLLAND
Groeneveld, van der Poll & Co., Amsterdam, De Ruijterkade 41, 42.

INDIA
Ewing & Co. Ltd., Calcutta. 4, Clive Row.
The Consolidated Mills Supplies Ltd., Bombay. Yusuf Building, Churchgate Street, Fort.

JAPAN
Gadelius & Co., Tokyo, 41, Akashi-cho Tsukiji.
Kobe, 58 B, Naniwa machi.
Dairen, 45, Yu-ku, Satsumacho.

NEW ZEALAND
Turnbull & Jones, Wellington, 19, 21, 23 Blair Street.

NORWAY
A/S Per Kure, Norsk Motor- og Dynamofabrik, Christiania, Universitetsgate 24.

PERU
Graham, Rowe & Co., Lima. Villalta 282.

PORTUGAL
Jayme da Costa L:tda, Lisbon, 16 Rua dos Correeiros 26.

RUSSIA
Société Russe d'Électricité Acea, Leningrad, Uliza Gogolja 7.

SOUTH-AFRICA
Reunert & Lenz, Johannesburg. Consolidated Buildings.

SPAIN
Sociedad Española de Electricidad Asea, Madrid, Calle Montalban 13.

BESIDES REPRESENTATIVES IN:

GREECE. LATVIA. MEXICO.

Vesteras 1924, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

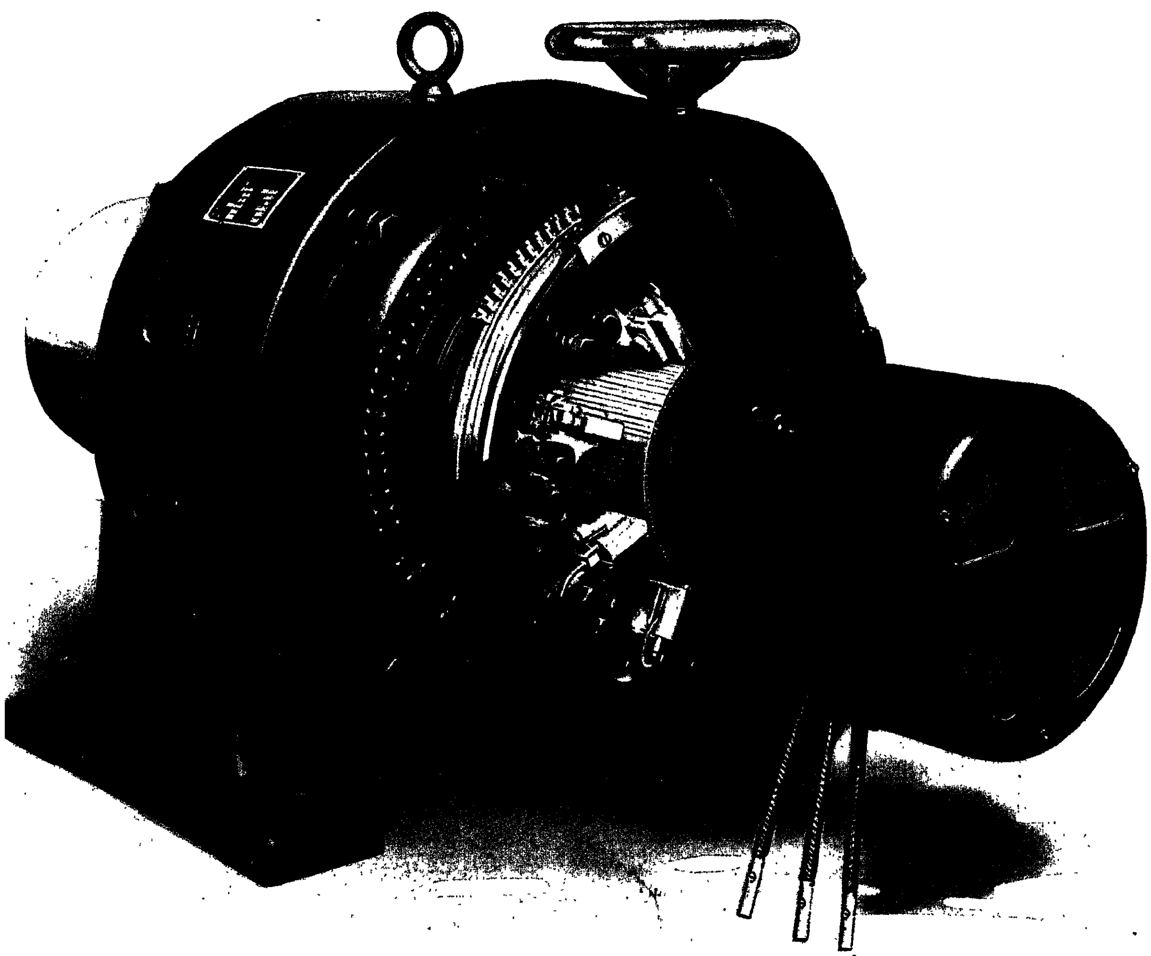
ALLMANNA SVENSKA ELEKTRISKA A.B.
VESTERAS — SWEDEN

SWEDISH GENERAL ELECTRIC LTD
5, CHANCERY LANE—LONDON

OCTOBER

All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesteras, Sweden.
Permission is given to reprint articles or extracts from this journal, on condition that the name — Asea-Journal — is clearly stated.

1924



Three-phase Commutator Motor Type FS, Form B, Arrangement 210.

THE VARIABLE-SPEED, THREE-PHASE, SHUNT COMMUTATOR MOTOR.

Introduction.

The problem of speed regulation with three-phase motors is a very old one. The ordinary induction motor, being the most widespread and well-known three-phase motor, has in general

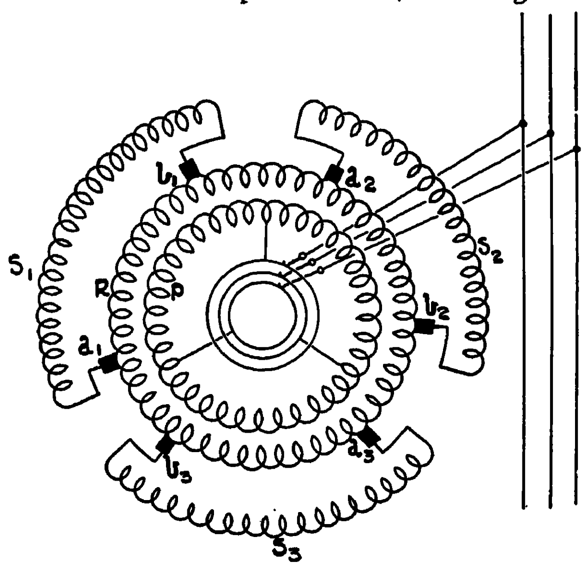


Fig. 1.

been used as a basis where speed regulation was to be considered, and, in fact, the development along this line has given the best results.

The simplest method of obtaining speed variation with an induction motor is to insert a resistance in the secondary circuit. This method, however, suffers from the disadvantage that the speed depends too much upon the load — the speed at no load approaching synchronism. When explaining this simple fact it is only necessary to state that the rotor windings and

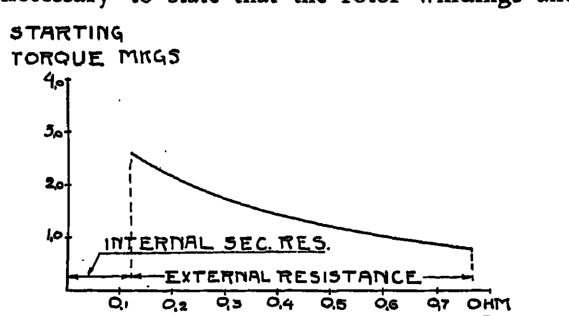


Fig. 2.

the external resistance form one closed circuit, so that the total sum of all voltages in this circuit must be equal to zero, or, in other words, the external voltage (= the voltage drop in the regulating resistance) is equivalent to the E.M.F.s induced in the rotor winding. If the external voltage is increased, the induced E.M.F. in the rotor must change in the same proportion. Considering that the rotor E.M.F. is proportional to the slip, this will also increase, *i. e.* the speed of the rotor decreases.

If the external voltage impressed on the rotor winding is varying with the current, as, for instance, the volt drop of a regulating resistance, the speed can not be stable but dependent upon the load.

A stable speed regulation is obtainable by inserting a stable voltage in the rotor or second-

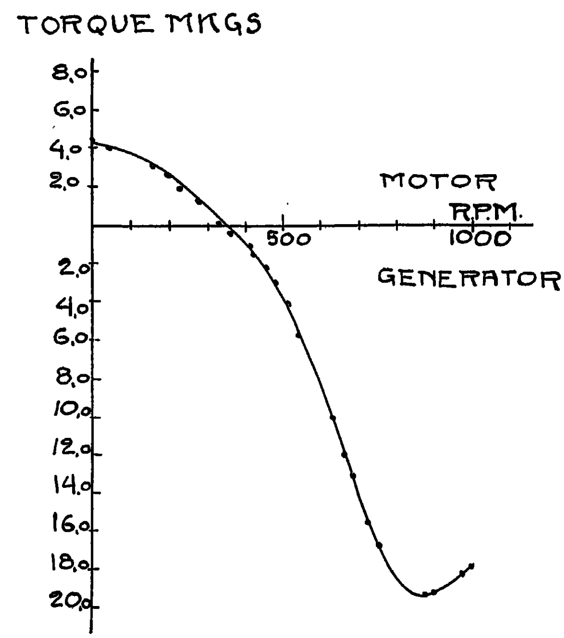


Fig. 3. Brushes in the position for min. undersynchronous speed ($\alpha = + 180$ el. degr.)

ary circuit. To this effect it is necessary to use, instead of the secondary regulating resistance, a concatenated commutator motor or generator connected to either the same shaft as the induction motor or to a constant speed motor. It is also possible to use a frequency converter connected to the shaft of the induction motor and with the same number of poles as the latter. A frequency converter is, in this case, a rotary converter with a laminated field without salient poles and without a stator winding.

Regarding the last mentioned method of speed regulation it was discovered about the year 1911, that the induction motor could be combined with the regulating frequency converter in one single machine (invention by K. H. Schrage of

the Asea). The necessary condition is that the character of a frequency converter be kept: *i. e.* the primary circuit must be located in the rotor, thus necessitating sliprings for the energy supply to the motor.

Arrangement of Windings.

The rotor has two windings, the one — the primary winding — an ordinary three-phase winding and connected to the sliprings, and the other — the regulating winding — arranged as a DC winding connected to a commutator. The secondary winding is located in the stator and consists of three independent phases. Both ends of each stator-phase are taken out and

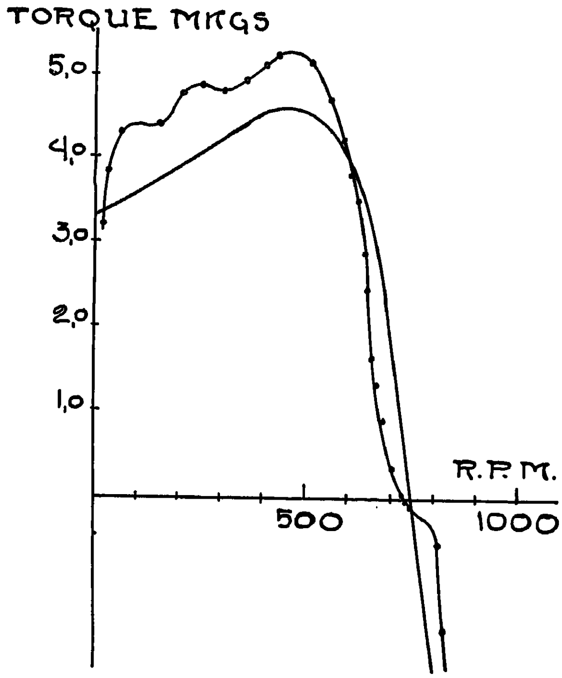


Fig. 4. Brushes in the position for synchronous speed ($\alpha = 0$) as calculated from motor data.

connected to the required number of brush sets. The two sets of brushes belonging to one phase are moveable either towards or from each other, as desired. The total amount of brush rotation is such as to make the angle between the corresponding brushes variable from + 180 el. degr. to — 180 el. degr. Diagram, fig. 1, shows the arrangement of windings for a two-pole motor.

Range of Speed Variation.

The voltage and the frequency at the sliprings being constant it is obvious that the flux, set up by the resultant ampere turns, revolves relative to the rotor with a constant speed dependent upon the number of poles and the frequency, but independent of the speed of the rotor. The flux induces in the primary winding an E.M.F. that counter-balances the slipring supply voltage, which is constant. As for a certain winding the induced E.M.F. is proportional to the flux times the frequency, it

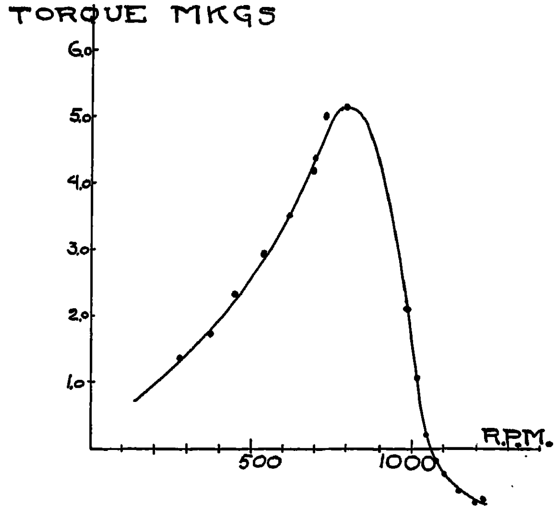


Fig. 5. Brushes in the position for max. oversynchronous speed ($\alpha = -180$ el. degr.)

will be understood that the flux must remain practically constant in spite of the varying speed. Since the flux always rotates with a constant speed relative to the rotor, the E.M.F. induced in any turn of the rotor windings must remain at the same value. Thus, the voltage between the commutator bars remains constant whether the rotor is standing still or at maximum speed, and, what is of importance, the voltage between the brushes belonging to one phase is only dependent upon the distance or the angle between those brushes.

Say, for example, that the maximum voltage

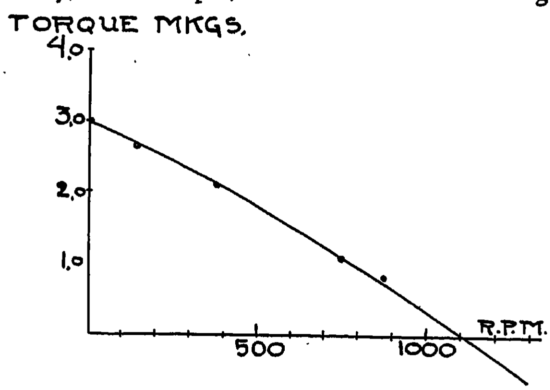


Fig. 6. Brushes in the pos. for max. oversynchronous speed. Extra sec. resistance = 0.48 ohms.

obtainable between the brushes is equal to half of that of a stator (secondary) phase at standstill. If the motor is switched in with full voltage, only half the secondary voltage is balanced by

the brush voltage and the other half is to be consumed by the ohmic and self-induction resistance, thus causing a heavy current in the secondary circuit. Together with the main flux

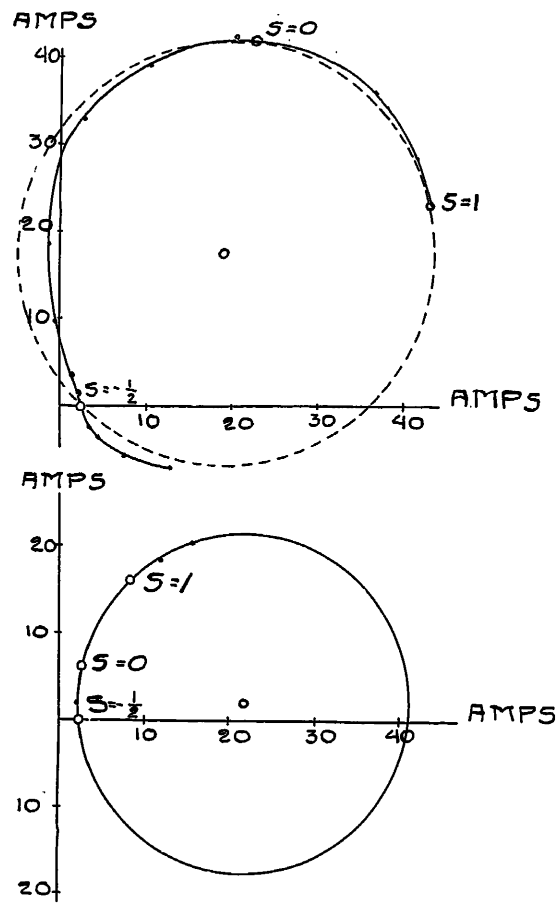


Fig. 7. Dotted circle as calculated from motor data.

this current produces a torque that accelerates the motor. The more the rotor is gaining speed, *i. e.* the slip, counted from synchronism, is decreasing, the more the secondary voltage is decreasing, because it is proportional to the slip. If the torque which the motor is starting against is very small, the speed can reach half the synchronous speed, the secondary voltage at this speed being equal to the brush voltage and fully balanced by the latter. If the motor is loaded, the speed must decrease just enough to allow sufficient secondary current to produce the necessary torque.

In order to further increase the speed it is only necessary to move the brushes towards each other, thus diminishing the voltage between them. When the brushes pass each other the voltage goes through zero and becomes reversed. The stator voltage must then be reversed too, which means that the motor runs at oversynchronous speed.

From what is said above, it is clearly understood that the brush voltage in proportion to the voltage of a stator phase at standstill determines the range of regulation, or more accurately speaking, if this ratio is called S_0 and the synchronous speed N_s, the speed is variable at no-load from

$$(1-S_0)\ N_s \text{ to } (1+S_0)\ N_s \text{ revs. per min.}$$

From no-load to full load the speed drops a certain amount varying with the ratio of the secondary losses to the total energy transmitted through the air gap. The speed drop in revolutions per minute is about the same at the lowest speed as at the highest one. For instance, a certain motor variable from 375 to 1,125 revs. at no load, drops about 75 revs. at maximum and minimum speed, *i. e.* the maximum full

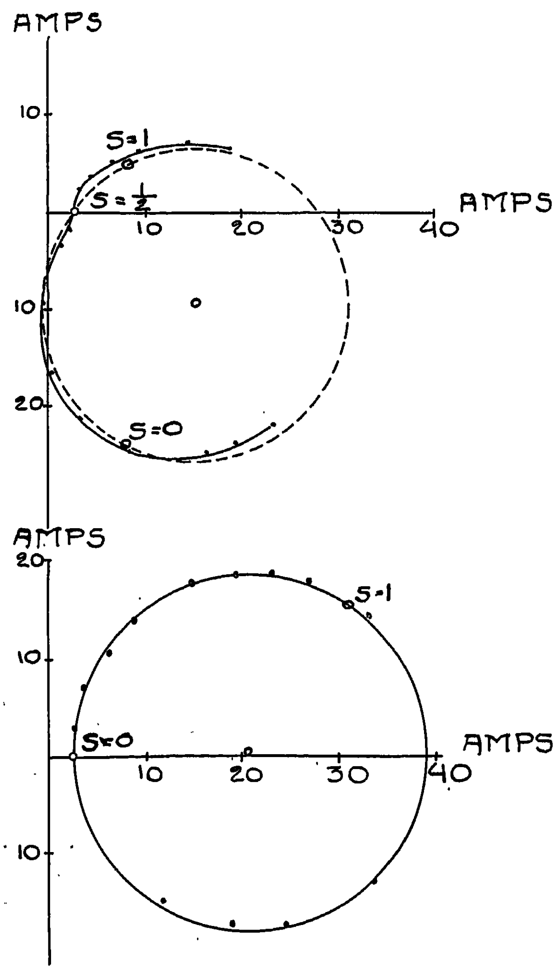


Fig. 8. Dotted circle as calculated from motor data.

load speed is 1,050 revs. and the minimum full load speed 300 revs. However, a motor variable within a certain range may be required to keep any speed promised at any condition from no

load to full load, so that in reality, the motor in this case should be rated at 1,050 to 375 revs (if the manufacturer is a scrupulous one). The speed drop at synchronous speed is somewhat smaller than that at maximum speed.

As already mentioned, the voltage between adjacent commutator bars is always kept at a constant value, so long as the slipring voltage is constant. In order to make the commutation sparkless, it is, therefore, necessary to keep the voltage per segment within a safe limit. The voltage per bar being limited, the maximum voltage between the brushes will also be limited and practically dependent upon the number of segments per pole. As the diameter of the commutator must be slightly smaller than that of the armature and the commutator bars not too thin, it is obvious that there is a practical limit for the range of regulation that should not be exceeded. But there is still another way of increasing this range. If the brush voltage cannot be increased, the stator voltage may be lowered in order to increase the value of S_0. However, by this method the output of the motor must be reduced nearly in the same proportion as that by which the stator voltage has been decreased.

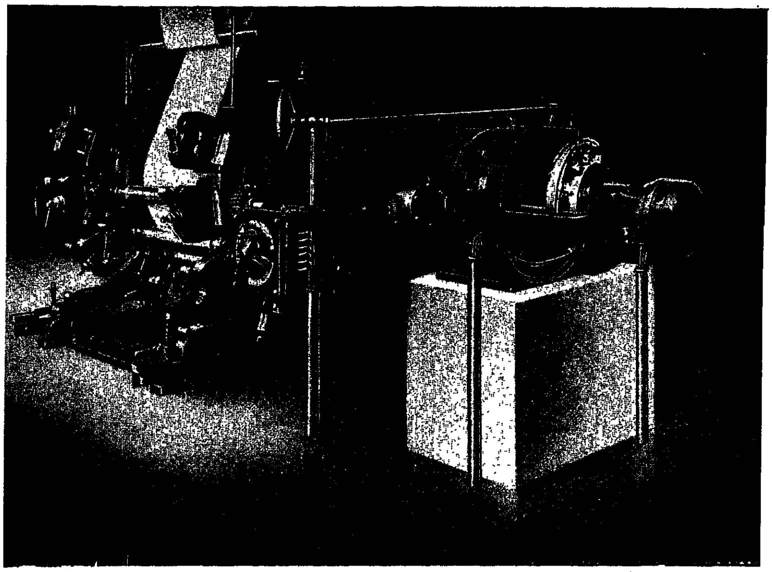


Fig. 9. Three-phase Commutator Motor 35/10 h. p. at 1,050/350 r. p. m. with reduction gear 1 : 42 coupled direct to a calico printing machine.

Regarding the commutation it should be observed that it is not possible to introduce any commutating poles or other means to facilitate it, except conductors with high resistance between the winding and the segments. In any case, it is of the utmost importance to determine by experiments covering a considerable period, what maximum segment voltage is permissable to secure the best possible commutation and the least possible brush wear. In this respect Asea has a great advantage in having had more than twelve years' experience.

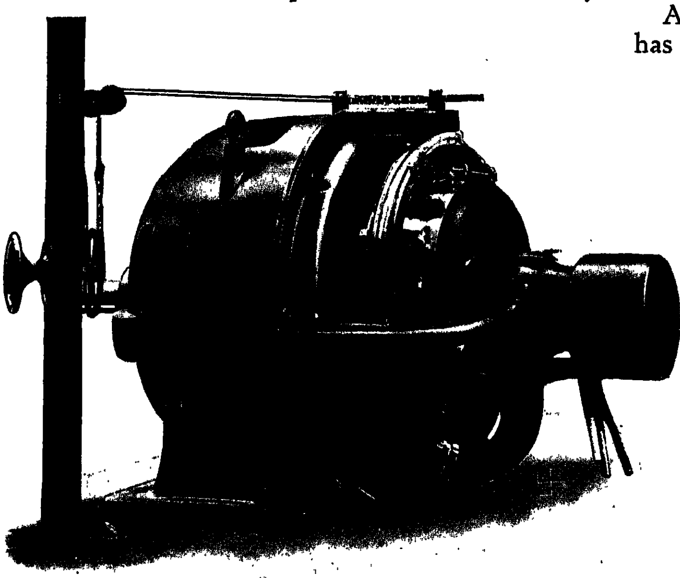


Fig. 10. Three-phase Commutator Motor, 50/17.8 h. p., 700/240 r. p. m., 50 cycles with remote control of the brush rocker by means of sprocket and chain, and wire rope.

Torque, etc.

At synchronous and higher speeds, the motor has a torque-slip curve very similar to that of the induction motor. Conditions are somewhat different below synchronism, especially at the brush position for the minimum speed. With this brush position, the torque slip-curve has no maximum point, but the torque increases steadily until the motor is at standstill. It is not possible to increase the torque by inserting an external secondary resistance, as shown by curve fig. 2. Curves, fig. 3, fig. 4, 5 and 6, give an idea of the variation of the torque with the speed at different brush positions and with secondary resistances.

Theoretical investigations and experiments have shown that the influence of the secondary resistance upon the characteristics of the motor is considerable. Fig. 7 shows the »circle» diagram with the brushes in the position for maximum speed, the upper diagram without, and the lower one with, an extra resistance in the secon-

dary circuit. The diagram shows that the power factor at over-synchronous speed very soon reaches unity or very near it: with an extra resistance the ordinate of the centre point of the circle is much smaller and the diagram becomes almost the same as that of the induction motor. In fig. 8 two diagrams are given — one for the minimum speed brush position ($\alpha=180°$) and the other for brushes short-circuited (standing in line $\alpha = 0$). At $\alpha = 180$ the running characteristics are not so good, cos φ being rather bad. However, it may be helped to some extent by an unsymmetrical brush position, but still it cannot be much better than about 0.8 without an undue increase of the secondary current especially at no load.

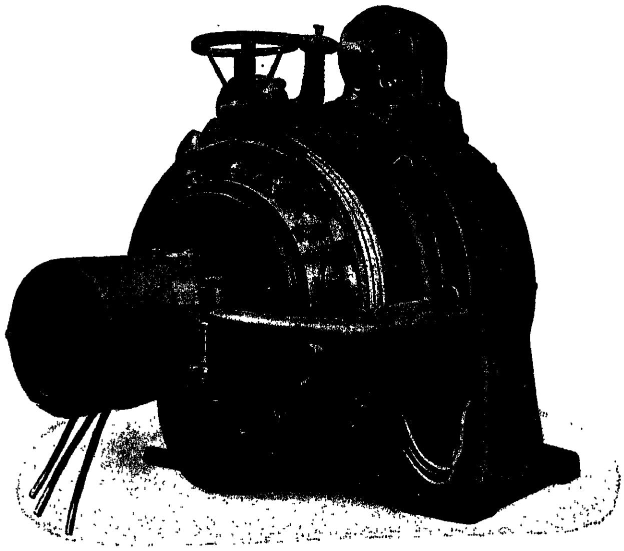


Fig. 11. Three-phase Commutator Motor, 50/16.6 h. p., 850/285 r. p. m. 50 cycles. The speed is regulated by means of contact pressure gauge and auxiliary motor.

The great sensitiveness of the motor to variations of the resistance in the secondary circuit together with the fact that the secondary resistance which, to a great extent consists of carbon contact resistance and varies considerably with the current, offers an explanation of the hunting

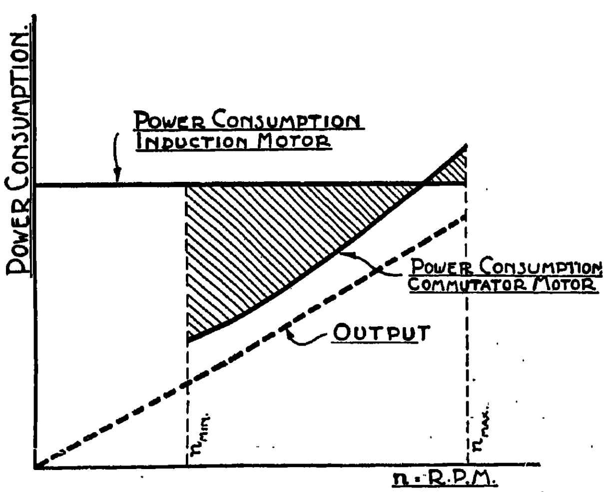


Fig. 12.

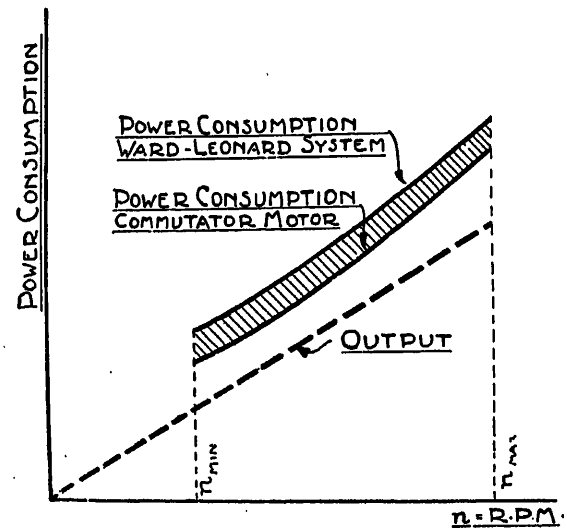


Fig. 13.

which has been observed on rare occasions with individual motors. The hunting is solely due to some bad contact in the secondary circuit and in some two or three cases where this has been experienced, it has always been successfully overcome by putting all bad contacts on the secondary side in good order.

Regarding the mechanical design it may be mentioned that the brush rocker arms are furnished with gear segments and are shifted by means of a pinion with handwheel (see front wiew) and for this reason the motor must be installed so that this handwheel is easily accessible for regulation. If this is not possible, then it will be necessary to use shaft and bevel gears for remote control (see fig. 9) or else the handwheel can be exchanged for a sprocket and chain so that the brushes can be shifted by means of a wire rope, which can be carried over block pulleys to almost any position desired (see fig. 10). The speed of the commutator motor shown in fig. 11 is regulated by means of a small auxiliary motor, which in turn is operated by a contact pressure gauge and relay.

The most characteristic features of this motor are as follows:

1. The motor can be started without rheostats, by connecting in the motor on the line with the brushes in the start position, when the motor immediately starts and accelerates to about $^1/_3$ of the maximum speed. With 1.5 times normal

full load line current, the motor gives a starting torque which is equal to twice full load torque for the small motors up to about 25 h.p., 1.5 times full load torque for the larger nonreversible motors, and full load torque for the larger reversible motors. If very slow starting is desired, this can be secured by means of a starting rheostat.

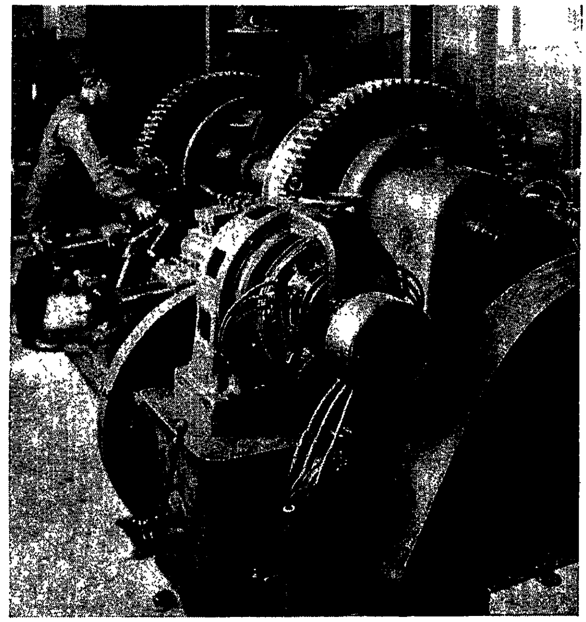


Fig. 14. Three-phase Commutator Motor 24/8 h. p., driving a wheel-lathe.

2. Very *simple* and *absolutely continuous speed regulation*, as explained above, is secured by *shifting the brushes* only, and, therefore, is accomplished without any regulating apparatus whatsoever and consequent losses in same. The regulation is done while the motor is *running under load.*

3. *Wide regulation possibilities.* The speed can be regulated by shifting the brushes only, from the maximum speed down to about 1/3 and in special cases even down to 1/4 of the maximum speed. If it should ever be necessary to run at still lower speeds, as is the case when starting certain textile and paper machines, this can easily be accomplished by means of a rheostat, such as is used with slip-ring type induction motors. In this case, however, the speed of the commutator motor will become dependent on the load, in the same way as when a rheostat is used for speed regulation with an induction motor.

4. The motor has *shunt characteristics*, its speed is therefore, practically independent of variations in the load. The change in speed from no load to full load is only about 5 to 8 % of the motor's maximum speed.

5. The motor can give *constant torque at any speed*, the horsepower output is, therefore, proportional to the speed. A shunt regulated direct current motor gives full torque only at the lowest speed.

6. As previously mentioned, the speed regulation is effected without any extra losses in the regulating apparatus. The overall efficiency is, therefore, much higher for a commutator motor than for an induction motor with regulating resistance in the secondary circuit, and also higher than for a Converter and direct current motor in the Ward-Leonard connection. Figs 12 and 13 show the input to a commutator motor at different speeds as compared with an induction motor and with a Ward-Leonard set respectively. The cross-sectioned area between the curves represents the energy which is saved on account of the higher efficiency of the commutator motor.

The *power factor* at the highest speed is 0.95 to 1.0 but is lower at the lower speeds. The shifting of the brushes is made unsymmetrical on the larger sizes in order to improve both the power factor and the starting torque. This method cannot, however, be used on reversible motors.

7. The *motor is made for standard voltages* so that it can be used without transformers on ordinary commercial circuits.

From the above it will be apparent that this motor can be used anywhere where a three-phase motor with large range of speed regulation is required. It will undoubtedly be specially welcome for installations where constant speed motors are chiefly installed, but where a few adjustable speed motors are also required, and for which it would otherwise be necessary to convert the alternating current into direct current.

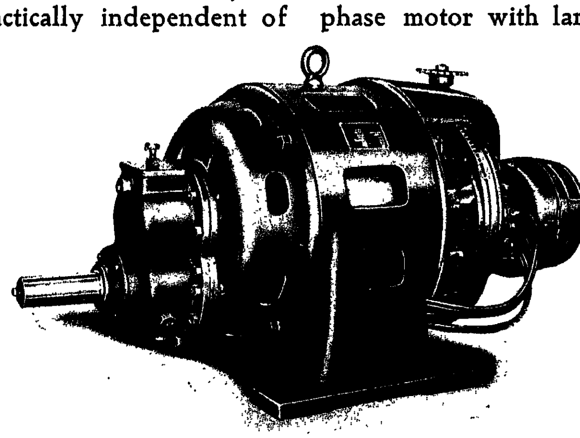


Fig. 15. Three-phase Commutator Motor 9/3 h. p. with reduction gear 1 : 0.8.

OVERHEAD CONSTRUCTION ON THE DRAMMEN RAILWAY.

The Norwegian State Railway running from Christiania V to Drammen is now electrified as far as Brageröen, a station about 2 km from

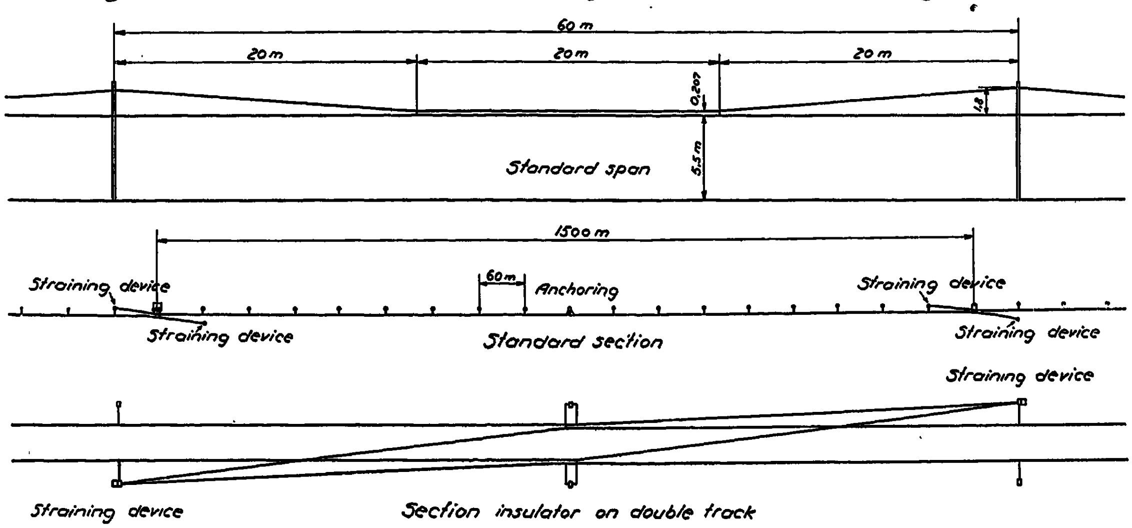


Fig. 1. Continuously strained system of trolley wire support.

Drammen. Electric trains, for the time being, are not able to run beyond this point, as the bridge over the Möllerholmen, which connects the northern and southern parts of Drammen, is not at present capable of carrying the weight of the electric locomotives.

The length of line over which trolley wire has been erected is about 51 km and of this the 13 km stretch between Christiania and Sandviken is double track construction, making the total length of main line single track electrified about 64 km. To this must be added 30 km of sidings at the 19 stations.

The following particulars apply to the overhead construction, which is in accordance with the specification drawn up by the Norwegian State Railways.

The single catenary system of suspension is used for the trolley wire.

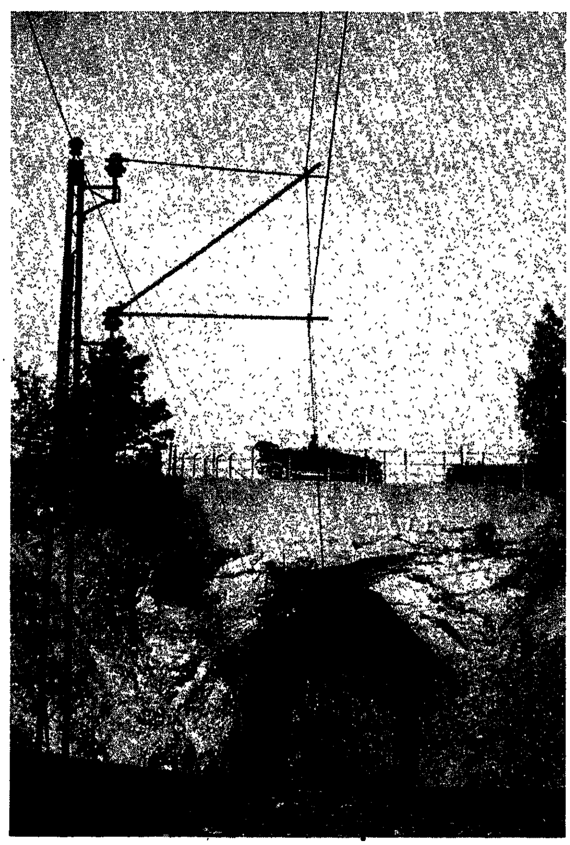


Fig. 2. Standard bracket-arm.

The insulators consist of two parts cemented together. The distance between the supporting poles is 60 m on the straight, with a suitable reduction at curves. The trolley wire is supported, as far as possible, on bracket arms. On stretches where there are more than two tracks the suspension is from cross structures.

The contact wire is supported on the continuously strained system with counter weight and spring straining devices. The height of the trolley wire is on open track $5^1/_2$ m and at stations and road crossings 6 m.

The size of the trolley wire and the design of the equipment has been determined by the following considerations.

Greatest wind pressure 125 kg/m².

Temperature limits $-35°$ and $+40°$ C.

Ice loading for the wire 200 + 50 dg/m. (d = the diameter of trolley wire in mm).

Ice loading for iron work 20 % of the weight of the structure.

The cross sectional area of the trolley wire

is on the main line 80 mm² copper. On sidings it is 50 mm² copper. The catenary or messenger cable has a cross sectional area on the main line of 50 mm² and on sidings 40 mm².

As regards insulators, it has been specified that these shall on test withstand a mechanical loading three times as great as the maximum load which could be thrown upon them under working conditions. Further they must withstand a sudden change in temperature between 0° and 100° C. The flash over voltage under rain test directed at an angle of 45° on to the insulators is not less than 40,000 volts.

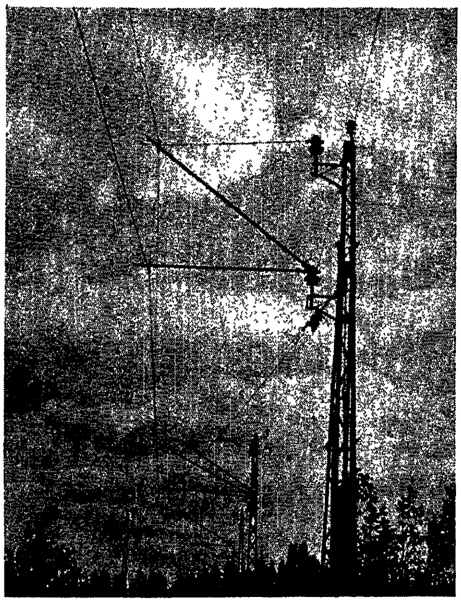


Fig. 3. Standard bracket-arm.

The rails are bonded by copper conductors having a cross sectional area of approximately 50 mm² and all structural ironwork and metal parts situated within a distance of 1 m of any live conductor are earthed to the track.

When Asea's representatives in Norway, A/S Per Kure, N.M.D.F. were settling the question of the trolley wire construction they had the advantage of the valuable experience which was obtained by Asea on the Riksgräns Railway, which was electrified in the years 1911 to 1914.

It was found however in calculating out the various parts used in construction on the basis of the stipulated requirements, that most of the details used on the Riksgräns Railway would have to be strengthened or redesigned. A new design was also necessary since here the insulators could not be placed over the centre of the track, as in the case of the Riksgräns Railway, because for some time to come steam trains will be running in addition to

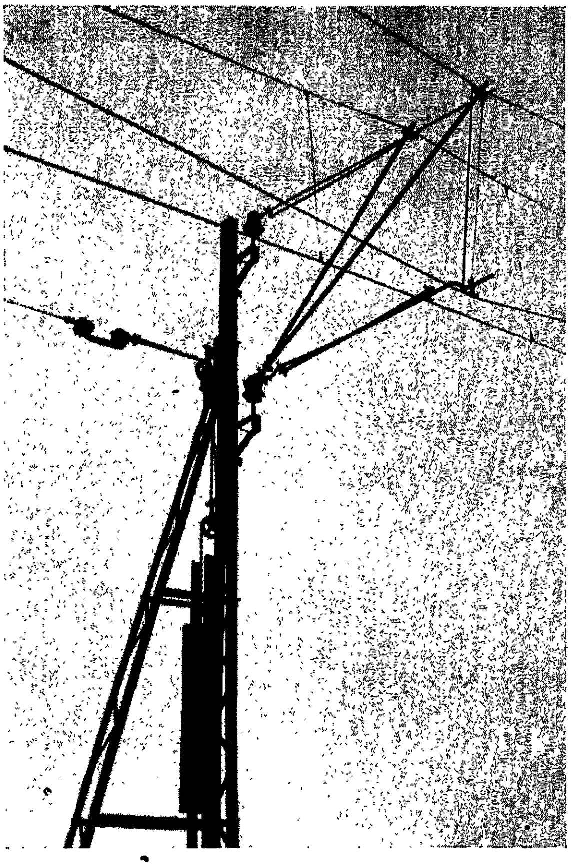


Fig. 4. Counter-weight straining device.

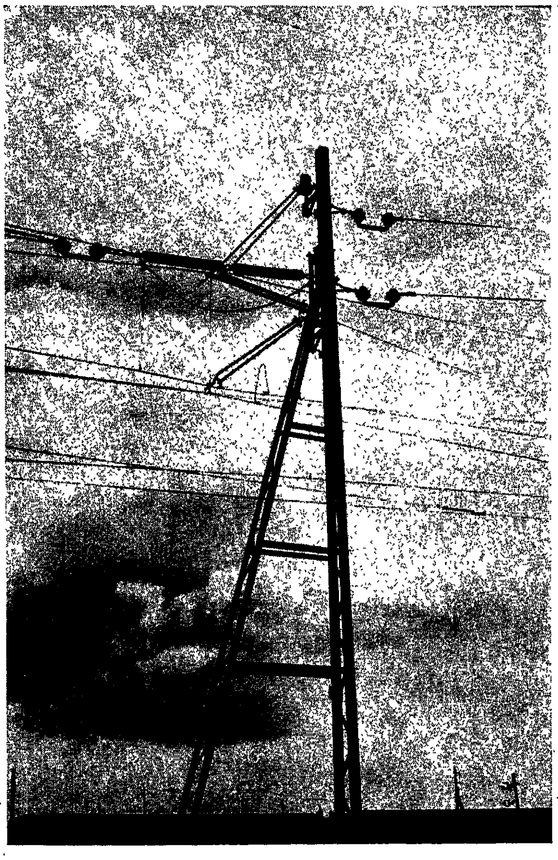


Fig. 5. Spring straining device.

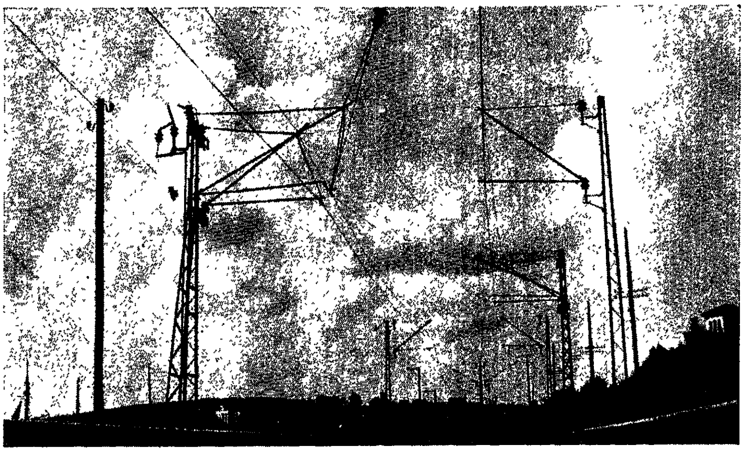


Fig. 6. Section insulator with line switch.

beneath. This requirement is also fulfilled as the push-off of the bracket arm, which is fixed to the bottom insulator, can swing in the vertical plane.

A further requirement for good contact properties is that the sag of the trolley wire must be the least possible, so that the collector bow which is held against the wire by springs need only make small vertical movements. This requirement is met by using catenary suspension. With a normal span of 60 m the trolley wire is supported every 20 m and is strained to an extent corresponding to a sag of 5 cm. Experience has shown that this amount will give satisfactory contact up to running speeds of 90 km per hour.

electric trains, and the arrangement would have allowed a deposit of soot to impair the insulation.

The object of the continuously strained system is to obtain great safety against breakage of the overhead wire and to ensure good running contact conditions at all temperatures. With the older systems, when the trolley wire is strained between the ends of each section, the sag of the wire is greater or less as the temperature varies. In the first case especially the contact between the collecting bow and the trolley wire is often particularly unsatisfactory, while at low temperatures dangerous loads are thrown on the poles and other constructional details.

All these disadvantages disappear in the continuously strained system, which has been used on the Drammen Railway and which is shown schematically in fig. 1.

As will be clear from the above diagram the temperature variations of the wire are taken up by weights which keep the tension on the trolley wire practically constant at all temperatures. In order that the line wire can move without hindrance in the longitudional direction, the bracket arms to which the wire is made fast must follow the movements of the wire and they are accordingly pivoted at the ends.

Figs 2 and 3 show the type of bracket arms employed. The bracket arms can swing about the two insulators which are mounted on the poles, one above the other, and whose supporting pins are loose in their brackets. To ensure good contact it is also essential for the trolley wire to be free to move vertically at the points of suspension, so that the locomotive collector bow will pass smoothly

The method of straining by weights referred to above is shown in fig. 4. On open stretches of track the trolley wire is erected in sections each 1500 m long. At each end of the section a counter weight is placed. In the middle of each section the trolley wire is anchored and accordingly each weight strains a length of 750 m.

A necessary condition of satisfactory working is that the system is installed throughout and that the shortest length of trolley wire in use is furnished with a straining device.

As it would be altogether too expensive to provide all the many short lengths of trolley wire occuring, for example, in station yards etc., and having a length of perhaps only 10 m or so, with weight straining devices, a different arrangement has been used for these, and a spring straining device adopted. On the Drammen Railway all sections of trolley wire under 200 m in length are strained by springs.

By this means, it is true, absolutely constant strain cannot be maintained on the trolley wire

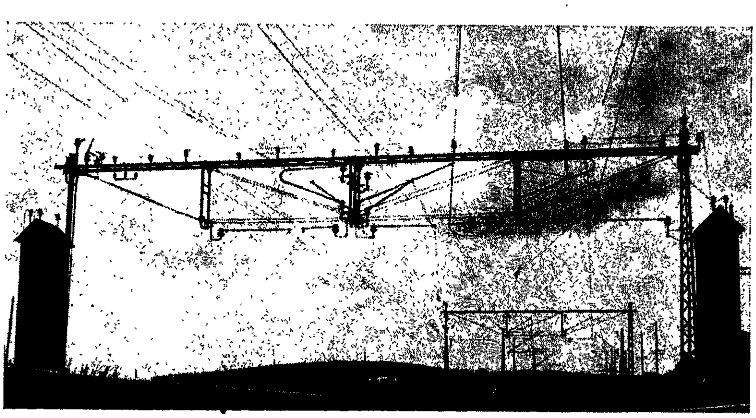


Fig. 7. Supporting structures.

at all temperatures, but experience has shown that the variation in the pull exerted by the spring is not sufficient to affect the contact obtained seriously. Fig. 5 shows a spring straining device having two springs, which is used on lengths of line between 100 and 200 m in length. Lengths of trolley wire such as those in question are anchored at the far end. Fig. 5 also shows how this anchoring is effected.

The sections of trolley wire are connected together through overhead switches as shown in fig. 6. This figure also shows the design of double bracket arm which is used at the ends of sections. Both lengths of trolley wire are here insulated from one another.

These section insulator bracket arms are so constructed that the two trolley wires are free to move in opposite directions. It will be seen that the overhead construction is comparatively simple and easy along the open sections of the line, but as a station is approached the proposition alters considerably, as is shown in figs. 7 and 8.

Here it is necessary to support trolley wires over a number of parallel tracks. At these points it would hardly do to make use of a pole at each point of support as there would be in some places a forest of poles which would obscure the driver's free view of the signals. In order to interrupt the view at these points as little as possible cross structures have been used to a great extent for supporting the contact wire.

It would occupy too much space to describe the various designs of cross girder construction employed and the method of their application. Fig. 9 is a view showing clearly the difficulties met with in electrifying a section outside Christiania V. Four tracks run here through a narrow neck leading towards Christiania and spread in the direction of Christiania V into a much larger system with a complicated lay-out of points and branch lines.

Fig. 8. Supporting structures.

An auxiliary feeder conductor having a cross sectional area of 50 mm² follows the trolley wire throughout its length and is supported on the trolley wire poles along the whole of the single track sections. This conductor is a part of the arrangement used on the Drammen Railway for neutralising the telephone disturbing effects.

As a protection against electro-magnetic induction in the telephone and telegraph wires track transformers are used. On the single track line from Sandviken to Brageröen a transformer with three windings is installed at every 1500 m. This transformer has a secondary winding for connecting in the track circuit and two primary windings of which one is connected in the trolley wire and the other in the auxiliary conductor.

On double track sections double transformers are installed one for each track with its own trolley wire.

The arrangement in principle is in accordance with fig. 10 which shows the connection diagram for part of the single track and double track sections.

Fig. 9. Arrangement of trolley wires at Christiania V.

The track transformers are contained in kiosks, the appearance of which is shown in fig. 11.

The auxiliary conductor makes it possible to localise faults on the overhead construction and limits the effect of breakdowns to a length of 1500 m. The same object is sought in the arrangement of the switch houses erected at the larger stations, from which any

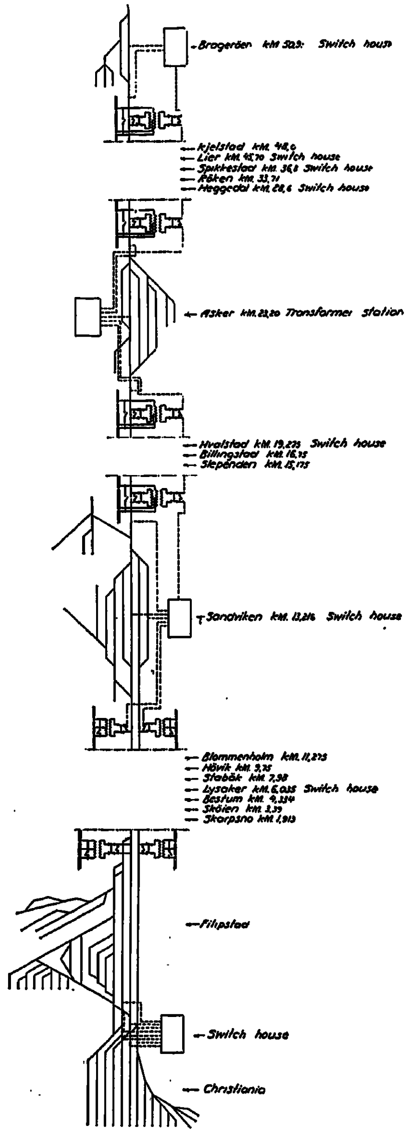


Fig. 10.

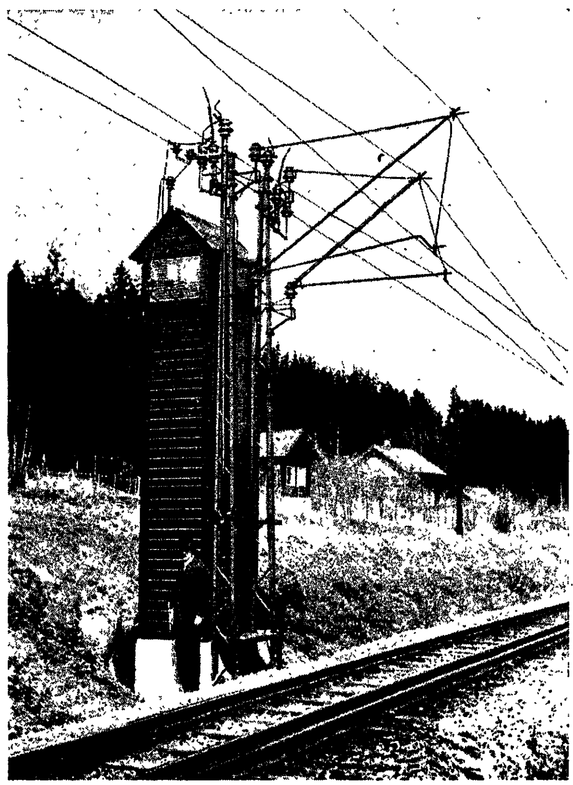


Fig. 11. Track transformer kiosk.

The welding apparatus is provided with an automatic regulating device and works practically without attention. The welding was carried out without interfering with the running of traffic and fig. 15 shows one of the welders at work. As far as railway practice in Scandinavia goes this method of welding the rail bonds has been used for the first time.

An important detail of the equipment, to which particular attention was given on the Drammen

particular track or group of tracks can be connected according to requirements. Fig. 12 shows the switchhouse at Lysaker and fig. 13 the diagram of connections for the arrangement of apparatus in this building.

The rails are bonded with copper bonds throughout. These bonds are arc welded to the side of the rail head, as shown in fig. 14. A portable welding outfit is used consisting of a 15 h.p. Penta motor with D.C. generator, series resistance, and other necessary apparatus, all carried in a railway wagon.

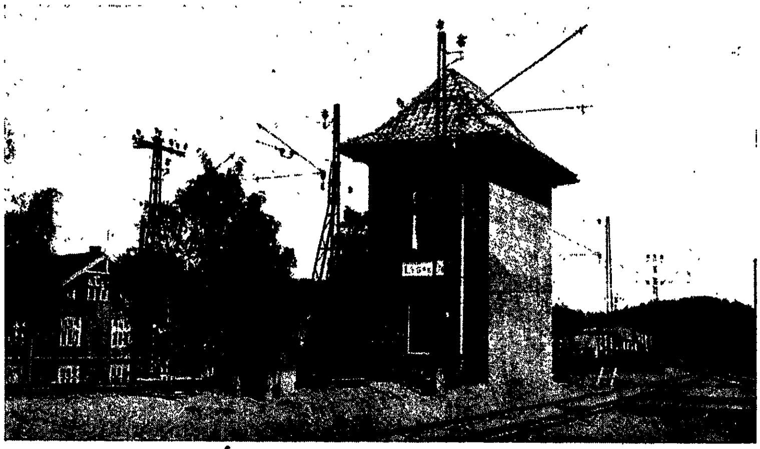


Fig. 12. Switch house at Lysaker station.

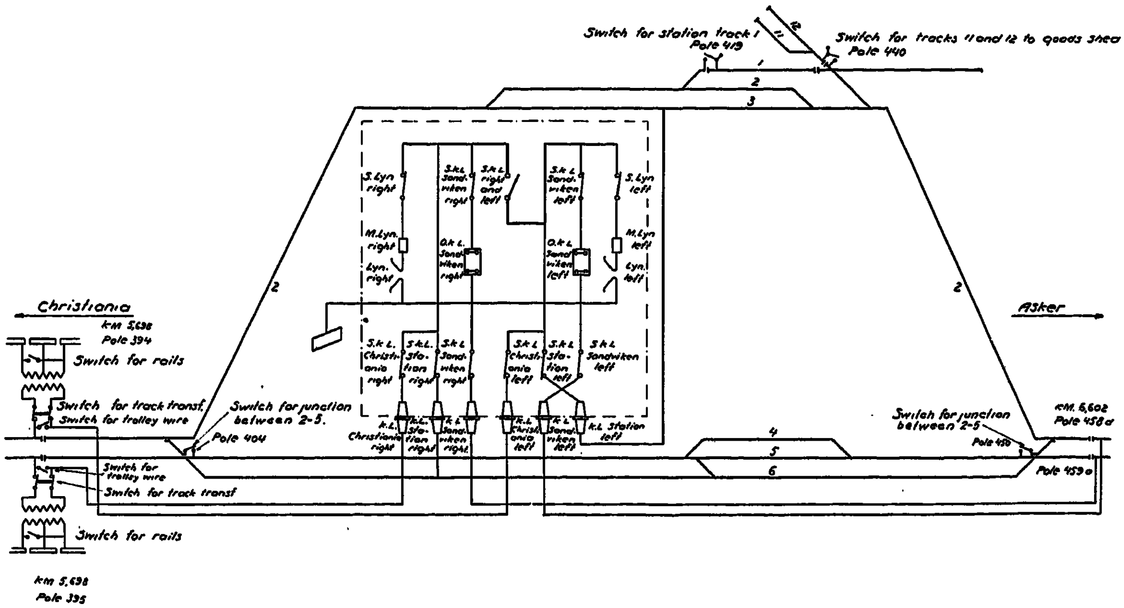


Fig. 13. Diagram of the connections at Lysaker station.

Railway is the type of safety device adopted to prevent accidents through touching the high tension current carrying conductors and structural ironwork. It followed from the question being so long drawn out that definite particulars for the protective devices were not finally settled until the last stage of the work. Here, as in other localities it was desired not to do too much or too little in the way of protection. The Drammen Railway runs partly through a thickly populated district and also partly through country which is very largely visited by sportsmen. About 40 bridges span the railway and for long distances the high road runs parallel to the line. From Sandviken to Brageroen the line runs through deep cuttings in rocky country. In many of these places the live conductors are so near to accessible places that the danger of interference, either accidental or intentional, is very great. The line is, of course, fenced in and on each pole a warning notice is fixed, but at the same time a railway is under an obligation to minimise the possibility of people running themselves into danger, even if they are trespassing. On the other hand the protective devices must not be of excessive size and the maintenance cost of them not be prohibitive.

After careful tests a standard screen consisting of fine mesh iron wire netting has been approved by the local authorities. Figs 16 and

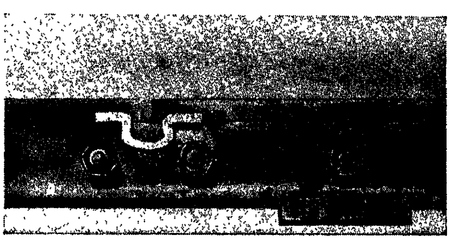


Fig. 14. Rail bond.

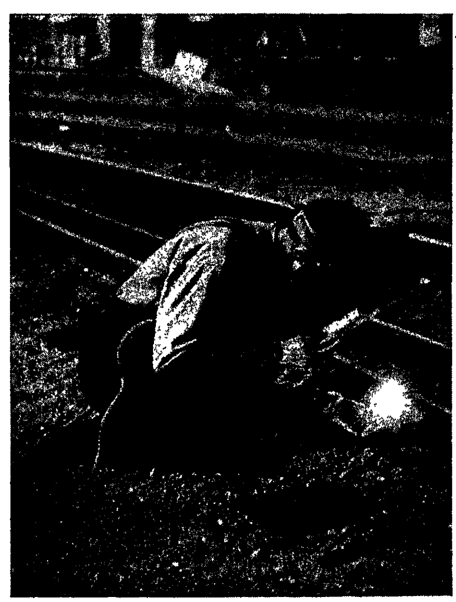


Fig. 15. Welder at work.

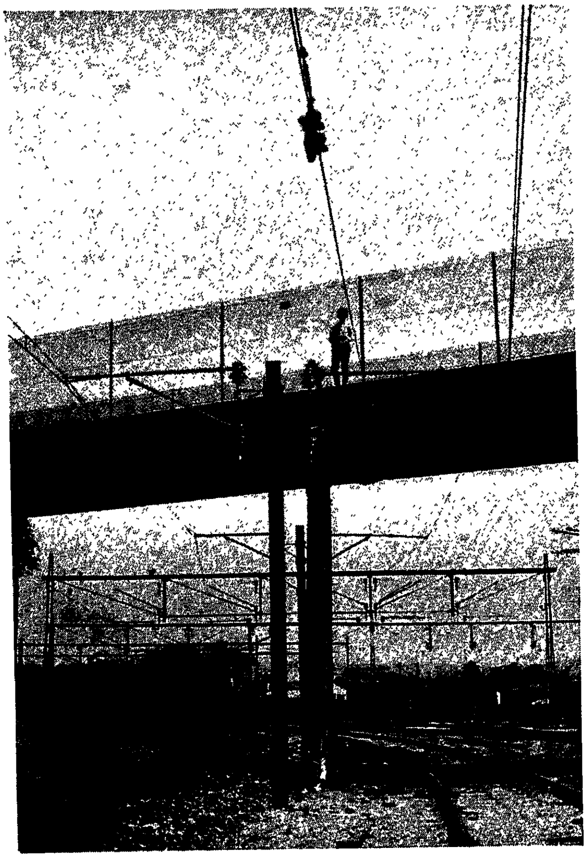


Fig. 16. Protecting screen at bridge.

17 show how this net is used where bridges cross over the line when the trolley wire lies

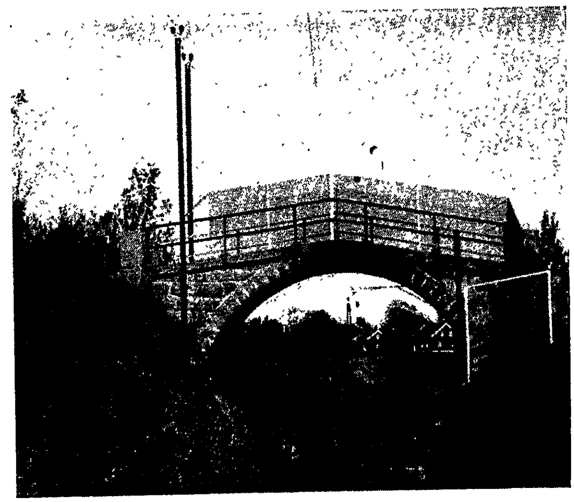


Fig. 17. Protecting screen at overbridge.

less than one metre from the footway of the bridge. The photograph of the bridge shown in fig. 17 shows a protecting screen in the form of a fence and also the method of taking the auxiliary feeder conductor over the bridge.

Fig. 18 shows a protecting net mounted upon a pole in such a way as to prevent persons who have climbed over the railway fencing coming by any means into contact with the lower insulator, which supports the bracket arm and which carries the full voltage of 15,000.

The whole overhead system has now been in use for a couple of years and during this time no trouble worthy of note has arisen.

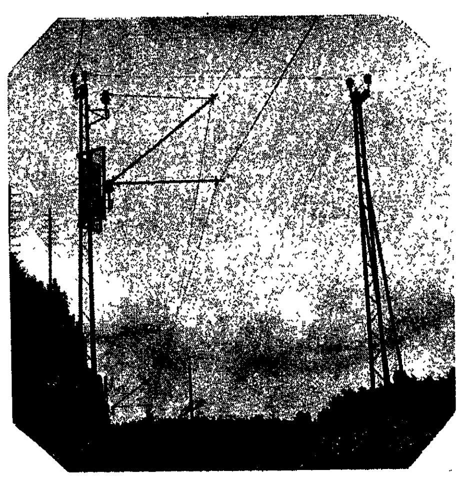
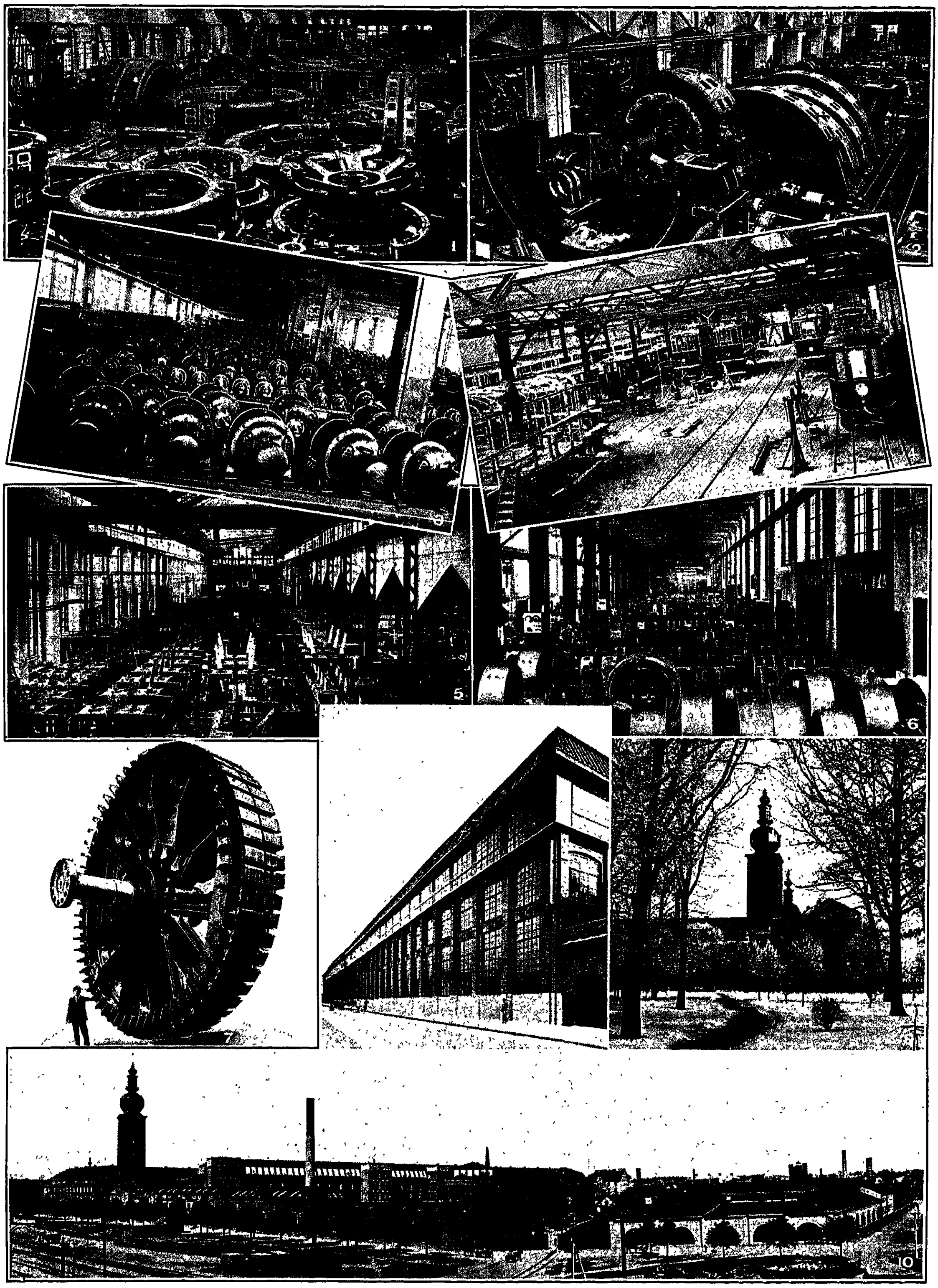


Fig. 18. Shield pattern screen.

CURRENT ILLUSTRATIONS.



SOME PICTURES FROM ASEA'S FACTORIES, VESTERAS, SWEDEN.
1) Workshop for large machines. 2) Some large machines under construction. 3) Testing room for small motors. 4) Manufacturing railway and tramcar bodies. 5) Manufacturing of large oilswitches. 6) Workshop for small and medium sized machines. 7) Rotor of a modern 12,000 kVA three-phase generator. 8) The »Mimer» works for small and medium sized machines. 9) The head office. 10) The head office, works for small and medium sized machines as well as foundries.

Vesteras 1924, Westmanlands Allehanda Printing Co.

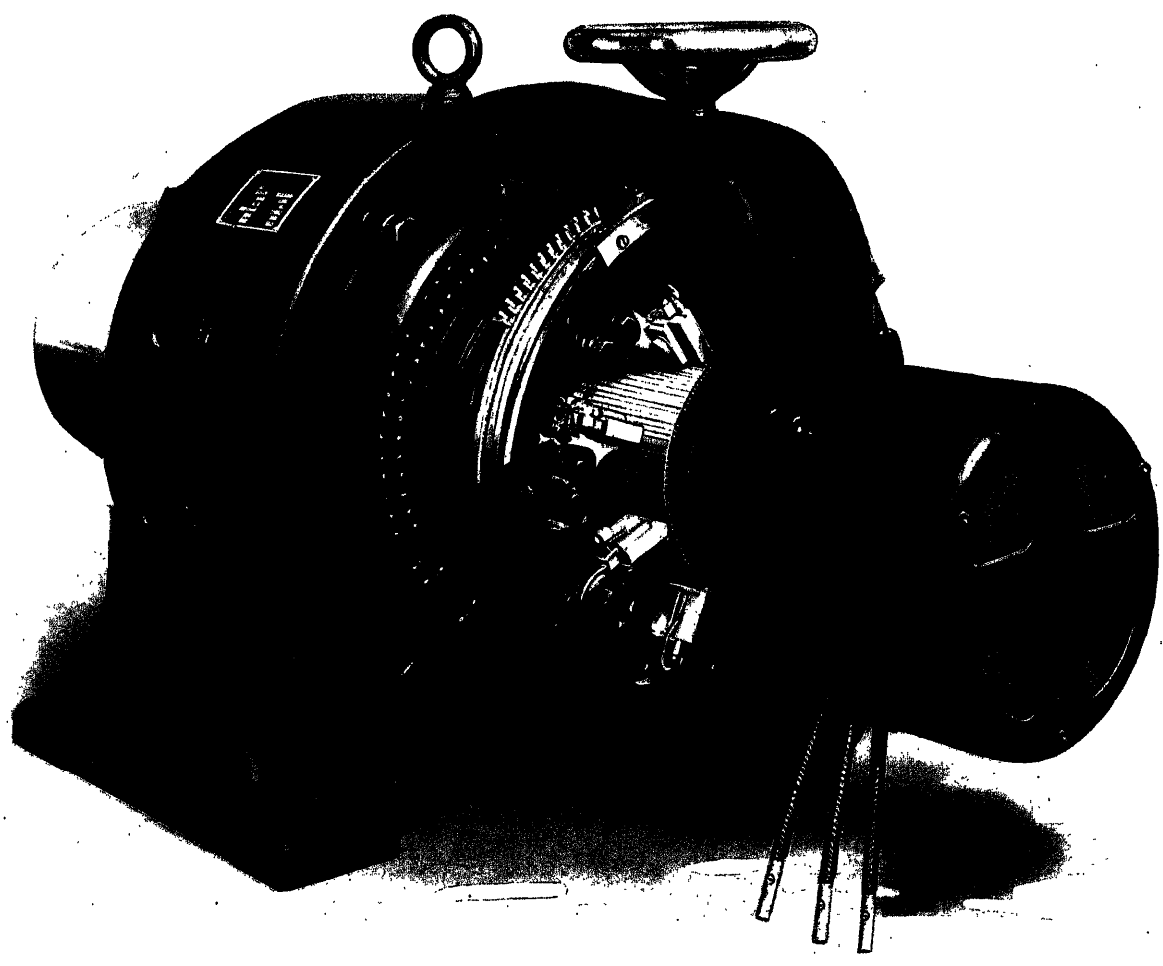
ASEA-JOURNAL

SWEDISH GENERAL ELECTRIC LTD
5, CHANCERY LANE—LONDON

OCTOBER

...e should be addressed to the Editor, Publicity Dept. Asea, Vesteras, Sweden.

1924



Three-phase Commutator Motor Type FS, Form B, Arrangement 210.

THE VARIABLE-SPEED, THREE-PHASE, SHUNT COMMUTATOR MOTOR.

Introduction.

The problem of speed regulation with three-phase motors is a very old one. The ordinary induction motor, being the most widespread and well-known three-phase motor, has in general

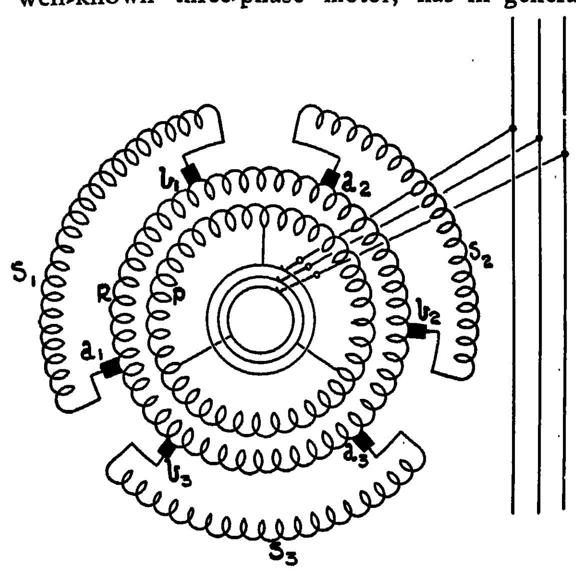


Fig. 1.

been used as a basis where speed regulation was to be considered, and, in fact, the development along this line has given the best results.

The simplest method of obtaining speed variation with an induction motor is to insert a resistance in the secondary circuit. This method, however, suffers from the disadvantage that the speed depends too much upon the load — the speed at no load approaching synchronism. When explaining this simple fact it is only necessary to state that the rotor windings and

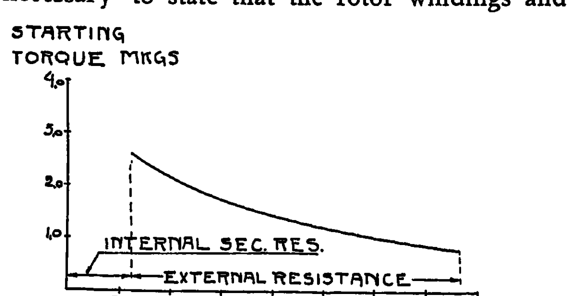


Fig. 2.

the external resistance form one closed circuit, so that the total sum of all voltages in this circuit must be equal to zero, or, in other words, the external voltage (= the voltage drop in the regulating resistance) is equivalent to the E.M.F.s induced in the rotor winding. If the external voltage is increased, the induced E.M.F. in the rotor must change in the same proportion. Considering that the rotor E.M.F. is proportional to the slip, this will also increase, *i. e.* the speed of the rotor decreases.

If the external voltage impressed on the rotor winding is varying with the current, as, for instance, the volt drop of a regulating resistance, the speed can not be stable but dependent upon the load.

A stable speed regulation is obtainable by inserting a stable voltage in the rotor or second-

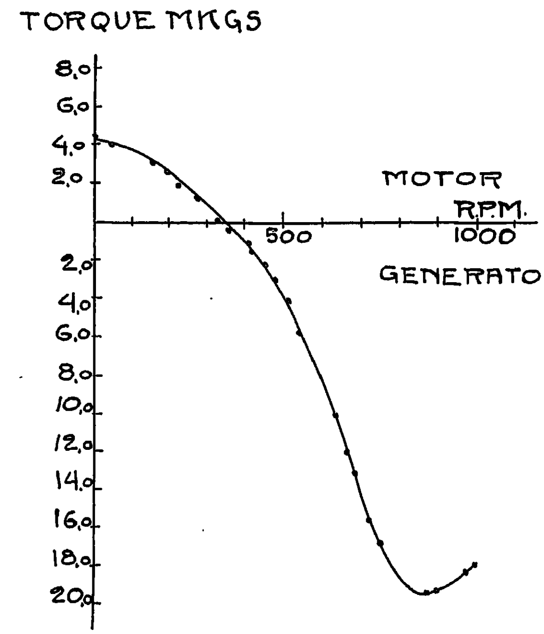


Fig. 3. Brushes in the position for min. undersynchronous speed ($\alpha = +180$ el. degr.)

ary circuit. To this effect it is necessary to use, instead of the secondary regulating resistance, a concatenated commutator motor or generator connected to either the same shaft as the induction motor or to a constant speed motor. It is also possible to use a frequency converter connected to the shaft of the induction motor and with the same number of poles as the latter. A frequency converter is, in this case, a rotary converter with a laminated field without salient poles and without a stator winding.

Regarding the last mentioned method of speed regulation it was discovered about the year 1911, that the induction motor could be combined with the regulating frequency converter in one single machine (invention by K. H. Schrage of

the Asea). The necessary condition is that the character of a frequency converter be kept: *i. e.* the primary circuit must be located in the rotor, thus necessitating sliprings for the energy supply to the motor.

Arrangement of Windings.

The rotor has two windings, the one — the primary winding — an ordinary three-phase winding and connected to the sliprings, and the other — the regulating winding — arranged as a DC winding connected to a commutator. The secondary winding is located in the stator and consists of three independent phases. Both ends of each stator-phase are taken out and

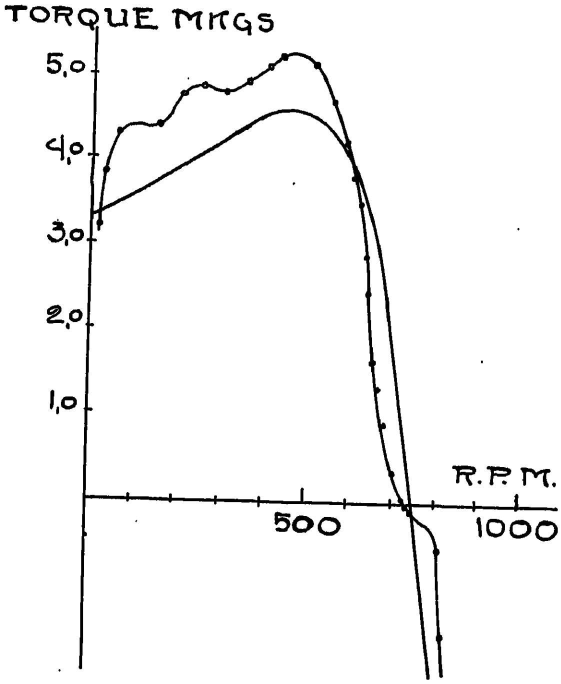


Fig. 4. Brushes in the position for synchronous speed ($\alpha = 0$) as calculated from motor data.

connected to the required number of brush sets. The two sets of brushes belonging to one phase are moveable either towards or from each other, as desired. The total amount of brush rotation is such as to make the angle between the corresponding brushes variable from + 180 el. degr. to — 180 el. degr. Diagram, fig. 1, shows the arrangement of windings for a two-pole motor.

Range of Speed Variation.

The voltage and the frequency at the sliprings being constant it is obvious that the flux, set up by the resultant ampere turns, revolves relative to the rotor with a constant speed dependent upon the number of poles and the frequency, but independent of the speed of the rotor. The flux induces in the primary winding an E.M.F. that counter-balances the slipring supply voltage, which is constant. As for a certain winding the induced E.M.F. is proportional to the flux times the frequency, it

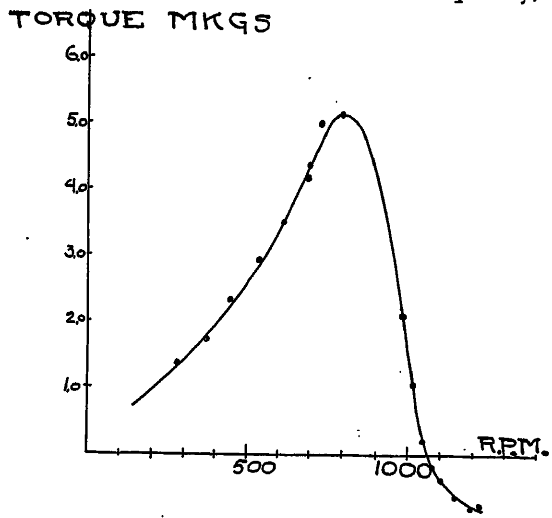


Fig. 5. Brushes in the position for max. oversynchronous speed ($\alpha = -180$ el. degr.)

will be understood that the flux must remain practically constant in spite of the varying speed. Since the flux always rotates with a constant speed relative to the rotor, the E.M.F. induced in any turn of the rotor windings must remain at the same value. Thus, the voltage between the commutator bars remains constant whether the rotor is standing still or at maximum speed, and, what is of importance, the voltage between the brushes belonging to one phase is only dependent upon the distance or the angle between those brushes.

Say, for example, that the maximum voltage

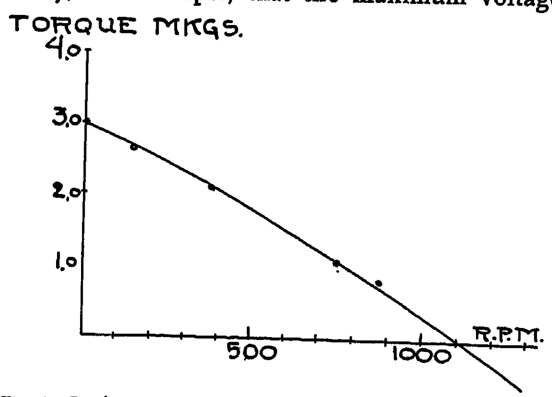


Fig. 6. Brushes in the pos. for max. oversynchronous speed. Extra sec. resistance = 0.48 ohms.

obtainable between the brushes is equal to half of that of a stator (secondary) phase at standstill. If the motor is switched in with full voltage, only half the secondary voltage is balanced by

the brush voltage and the other half is to be consumed by the ohmic and self-induction resistance, thus causing a heavy current in the secondary circuit. Together with the main flux

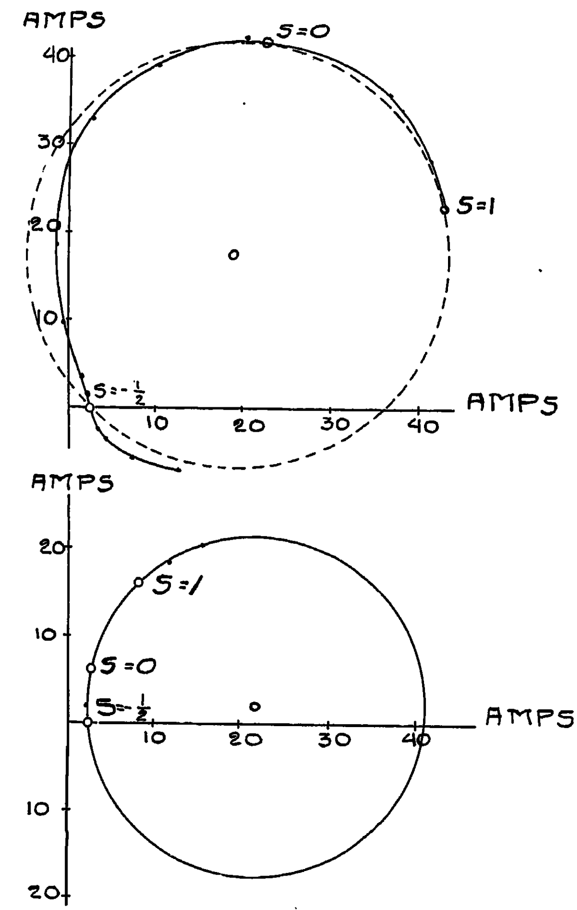


Fig. 7. Dotted circle as calculated from motor data.

this current produces a torque that accelerates the motor. The more the rotor is gaining speed, *i. e.* the slip, counted from synchronism, is decreasing, the more the secondary voltage is decreasing, because it is proportional to the slip. If the torque which the motor is starting against is very small, the speed can reach half the synchronous speed, the secondary voltage at this speed being equal to the brush voltage and fully balanced by the latter. If the motor is loaded, the speed must decrease just enough to allow sufficient secondary current to produce the necessary torque.

In order to further increase the speed it is only necessary to move the brushes towards each other, thus diminishing the voltage between them. When the brushes pass each other the voltage goes through zero and becomes reversed. The stator voltage must then be reversed too, which means that the motor runs at oversynchronous speed.

From what is said above, it is clearly understood that the brush voltage in proportion to the voltage of a stator phase at standstill determines the range of regulation, or more accurately speaking, if this ratio is called S_0 and the synchronous speed N_s, the speed is variable at no-load from

$$(1-S_0)\ N_s \text{ to } (1+S_0)\ N_s \text{ revs. per min.}$$

From no-load to full load the speed drops a certain amount varying with the ratio of the secondary losses to the total energy transmitted through the air gap. The speed drop in revolutions per minute is about the same at the lowest speed as at the highest one. For instance, a certain motor variable from 375 to 1,125 revs. at no load, drops about 75 revs. at maximum and minimum speed, *i. e.* the maximum full

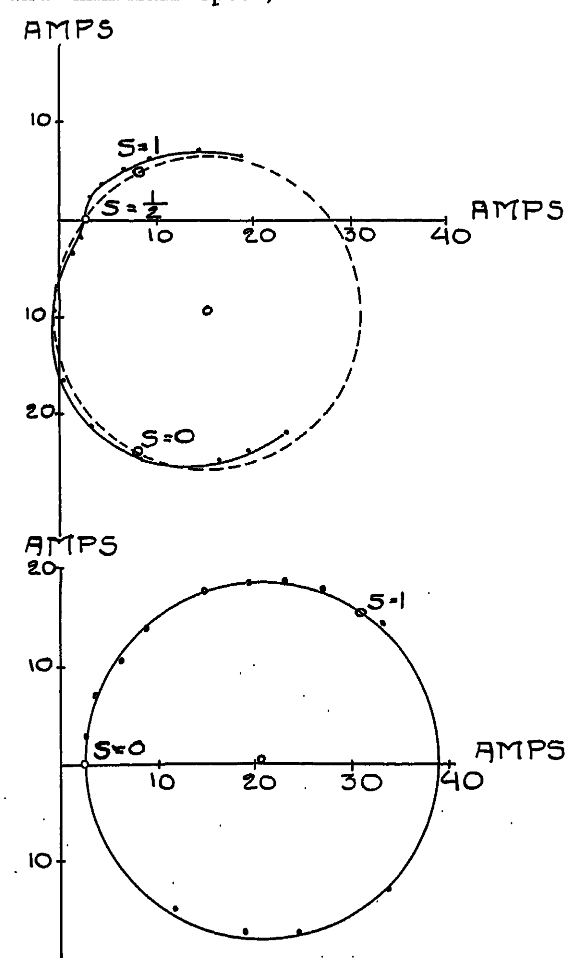


Fig. 8. Dotted circle as calculated from motor data.

load speed is 1,050 revs. and the minimum full load speed 300 revs. However, a motor variable within a certain range may be required to keep any speed promised at any condition from no

load to full load, so that in reality, the motor in this case should be rated at 1,050 to 375 revs (if the manufacturer is a scrupulous one). The speed drop at synchronous speed is somewhat smaller than that at maximum speed.

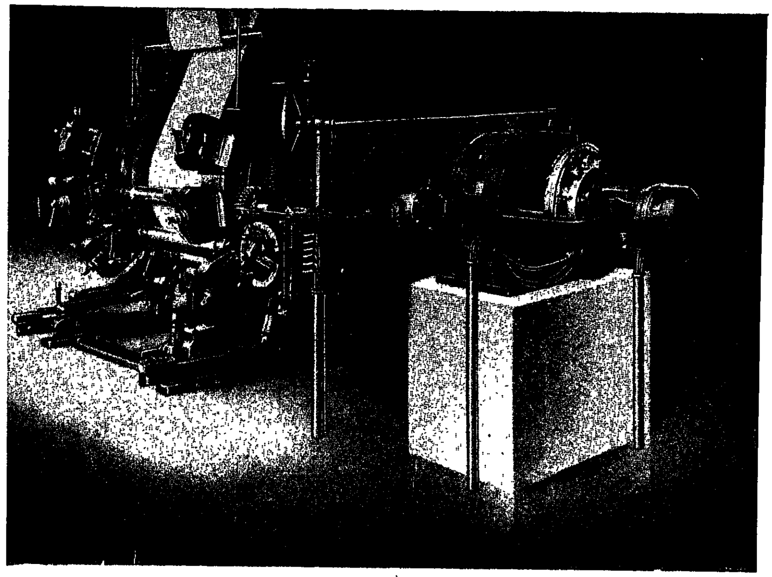


Fig. 9. Three-phase Commutator Motor 35/10 h. p. at 1,050/350 r. p. m. with reduction gear 1 : 42 coupled direct to a calico printing machine.

As already mentioned, the voltage between adjacent commutator bars is always kept at a constant value, so long as the slipring voltage is constant. In order to make the commutation sparkless, it is, therefore, necessary to keep the voltage per segment within a safe limit. The voltage per bar being limited, the maximum voltage between the brushes will also be limited and practically dependent upon the number of segments per pole. As the diameter of the commutator must be slightly smaller than that of the armature and the commutator bars not too thin, it is obvious that there is a practical limit for the range of regulation that should not be exceeded. But there is still another way of increasing this range. If the brush voltage cannot be increased, the stator voltage may be lowered in order to increase the value of S_0. However, by this method the output of the motor must be reduced nearly in the same proportion as that by which the stator voltage has been decreased.

Regarding the commutation it should be observed that it is not possible to introduce any commutating poles or other means to facilitate it, except conductors with high resistance between the winding and the segments. In any case, it is of the utmost importance to determine by experiments covering a considerable period, what maximum segment voltage is permissable to secure the best possible commutation and the least possible brush wear. In this respect Asea has a great advantage in having had more than twelve years' experience.

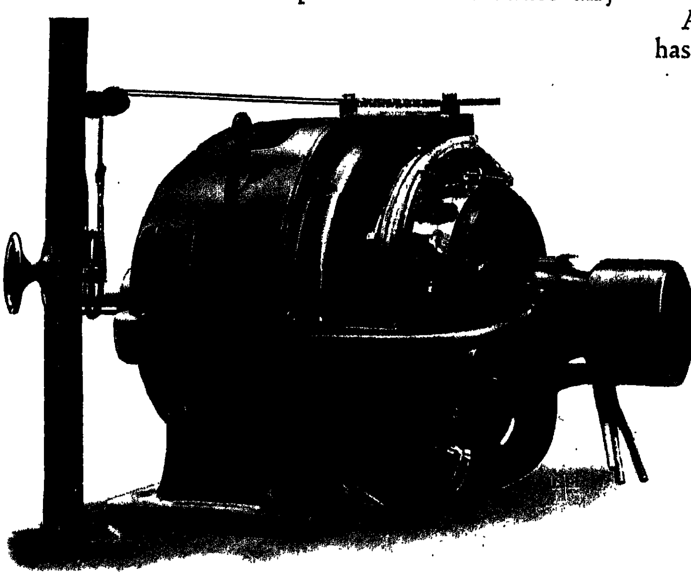


Fig. 10. Three-phase Commutator Motor, 50/17.3 h. p., 700/240 r. p. m., 50 cycles with remote control of the brush rocker by means of sprocket and chain, and wire rope.

Torque, etc.

At synchronous and higher speeds, the motor has a torque-slip curve very similar to that of the induction motor. Conditions are somewhat different below synchronism, especially at the brush position for the minimum speed. With this brush position, the torque slip-curve has no maximum point, but the torque increases steadily until the motor is at standstill. It is not possible to increase the torque by inserting an external secondary resistance, as shown by curve fig. 2. Curves, fig. 3, fig. 4, 5 and 6, give an idea of the variation of the torque with the speed at different brush positions and with secondary resistances.

Theoretical investigations and experiments have shown that the influence of the secondary resistance upon the characteristics of the motor is considerable. Fig. 7 shows the »circle» diagram with the brushes in the position for maximum speed, the upper diagram without, and the lower one with, an extra resistance in the secon-

dary circuit. The diagram shows that the power factor at oversynchronous speed very soon reaches unity or very near it: with an extra resistance the ordinate of the centre point of the circle is much smaller and the diagram becomes almost the same as that of the induction motor. In fig. 8 two diagrams are given — one for the minimum speed brush position ($\alpha = 180°$) and the other for brushes short-circuited (standing in line $\alpha = 0$). At $\alpha = 180$ the running characteristics are not so good, cos φ being rather bad. However, it may be helped to some extent by an unsymmetrical brush position, but still it cannot be much better than about 0.8 without an undue increase of the secondary current especially at no load.

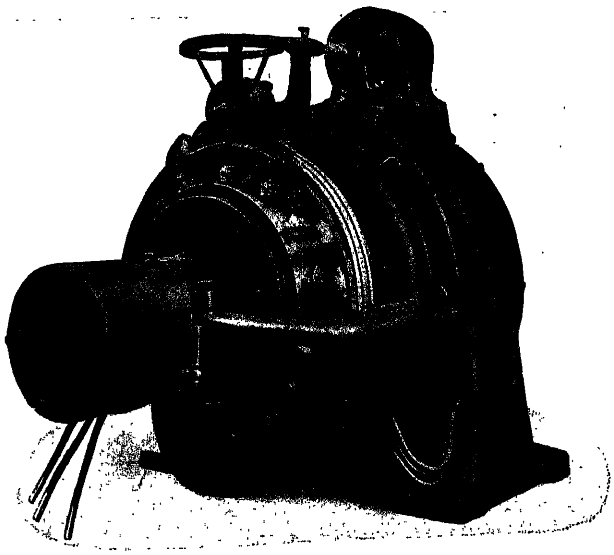


Fig. 11. Three-phase Commutator Motor, 50/16.6 h. p., 850/285 r. p. m. 50 cycles. The speed is regulated by means of contact pressure gauge and auxiliary motor.

The great sensitiveness of the motor to variations of the resistance in the secondary circuit together with the fact that the secondary resistance which, to a great extent consists of carbon contact resistance and varies considerably with the current, offers an explanation of the hunting

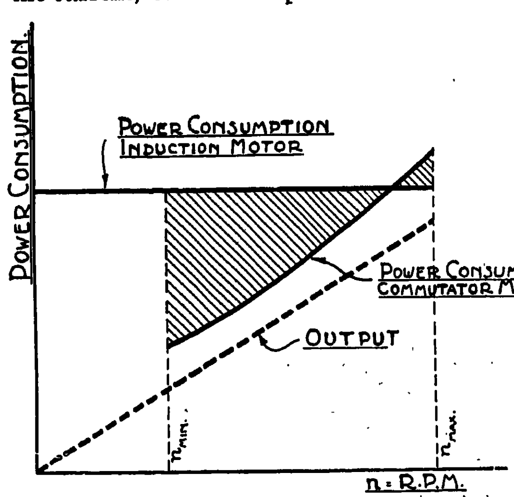


Fig. 12.

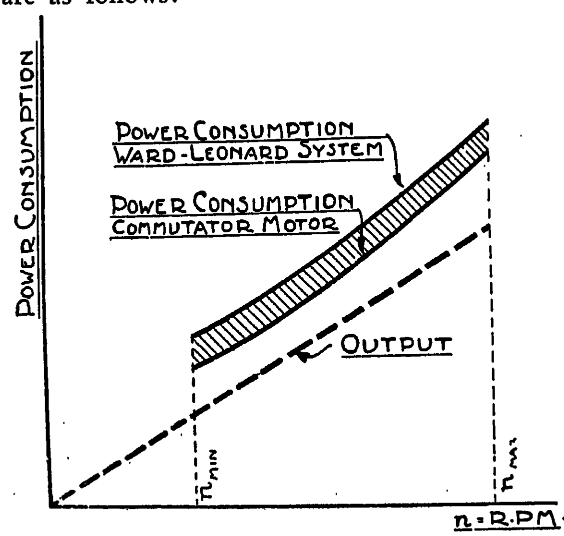


Fig. 13.

which has been observed on rare occasions with individual motors. The hunting is solely due to some bad contact in the secondary circuit and in some two or three cases where this has been experienced, it has always been successfully overcome by putting all bad contacts on the secondary side in good order.

Regarding the mechanical design it may be mentioned that the brush rocker arms are furnished with gear segments and are shifted by means of a pinion with handwheel (see front wiew) and for this reason the motor must be installed so that this handwheel is easily accessible for regulation. If this is not possible, then it will be necessary to use shaft and bevel gears for remote control (see fig. 9) or else the handwheel can be exchanged for a sprocket and chain so that the brushes can be shifted by means of a wire rope, which can be carried over block pulleys to almost any position desired (see fig. 10). The speed of the commutator motor shown in fig. 11 is regulated by means of a small auxiliary motor, which in turn is operated by a contact pressure gauge and relay.

The most characteristic features of this motor are as follows:

1. The motor can be started without rheostats, by connecting in the motor on the line with the brushes in the start position, when the motor immediately starts and accelerates to about $^1/_3$ of the maximum speed. With 1.5 times normal

full load line current, the motor gives a starting torque which is equal to twice full load torque for the small motors up to about 25 h.p., 1.5 times full load torque for the larger nonreversible motors, and full load torque for the larger reversible motors. If very slow starting is desired, this can be secured by means of a starting rheostat.

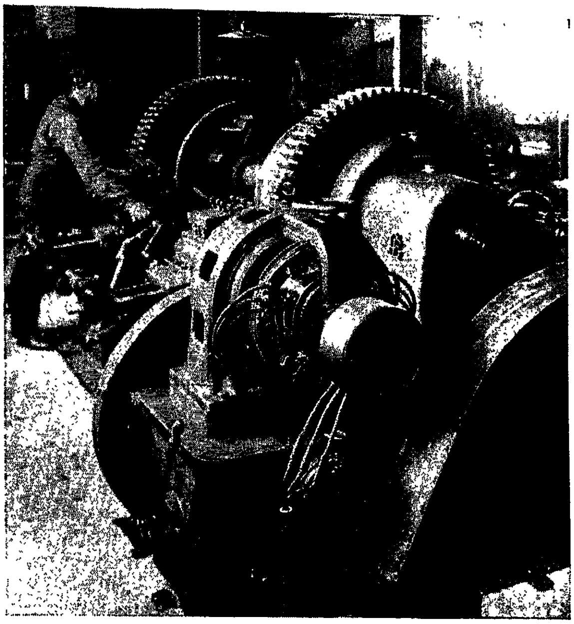


Fig. 14. Three-phase Commutator Motor 24/8 h. p., driving a wheel-lathe.

2. Very *simple* and *absolutely continuous speed regulation*, as explained above, is secured by *shifting the brushes* only, and, therefore, is accomplished without any regulating apparatus whatsoever and consequent losses in same. The regulation is done while the motor is *running under load.*

3. *Wide regulation possibilities.* The speed can be regulated by shifting the brushes only, from the maximum speed down to about 1/3 and in special cases even down to 1/4 of the maximum speed. If it should ever be necessary to run at still lower speeds, as is the case when starting certain textile and paper machines, this can easily be accomplished by means of a rheostat, such as is used with slip-ring type induction motors. In this case, however, the speed of the commutator motor will become dependent on the load, in the same way as when a rheostat is used for speed regulation with an induction motor.

4. The motor has *shunt characteristics*, its speed is therefore, practically independent of variations in the load. The change in speed from no load to full load is only about 5 to 8 % of the motor's maximum speed.

5. The motor can give *constant torque at any speed*, the horsepower output is, therefore, proportional to the speed. A shunt regulated direct current motor gives full torque only at the lowest speed.

6. As previously mentioned, the speed regulation is effected without any extra losses in the regulating apparatus. The overall efficiency is, therefore, much higher for a commutator motor than for an induction motor with regulating resistance in the secondary circuit, and also higher than for a Converter and direct current motor in the Ward-Leonard connection. Figs 12 and 13 show the input to a commutator motor at different speeds as compared with an induction motor and with a Ward-Leonard set respectively. The cross-sectioned area between the curves represents the energy which is saved on account of the higher efficiency of the commutator motor.

The *power factor* at the highest speed is 0.95 to 1.0 but is lower at the lower speeds. The shifting of the brushes is made unsymmetrical on the larger sizes in order to improve both the power factor and the starting torque. This method cannot, however, be used on reversible motors.

7. The *motor is made for standard voltages* so that it can be used without transformers on ordinary commercial circuits.

From the above it will be apparent that this motor can be used anywhere where a three-phase motor with large range of speed regulation is required. It will undoubtedly be specially welcome for installations where constant speed motors are chiefly installed, but where a few adjustable speed motors are also required, and for which it would otherwise be necessary to convert the alternating current into direct current.

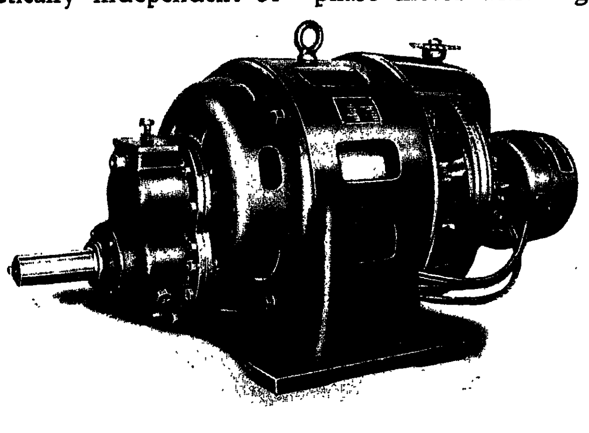


Fig. 15. Three-phase Commutator Motor 9/3 h. p. with reduction gear 1 : 0.6.

OVERHEAD CONSTRUCTION ON THE DRAMMEN RAILWAY.

The Norwegian State Railway running from Christiania V to Drammen is now electrified as far as Brageröen, a station about 2 km from

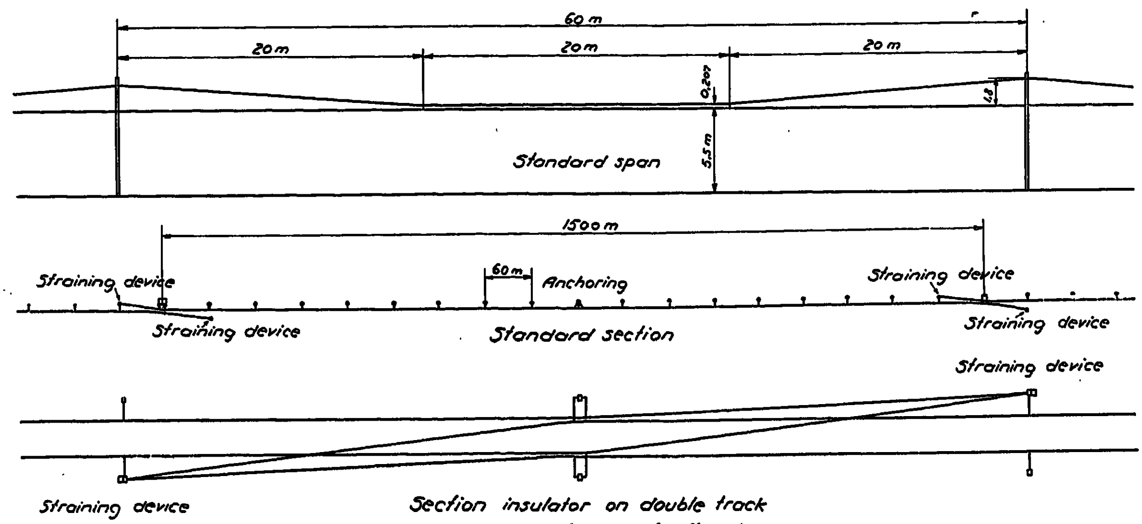


Fig. 1. Continuously strained system of trolley wire support.

Drammen. Electric trains, for the time being, are not able to run beyond this point, as the bridge over the Möllerholmen, which connects the northern and southern parts of Drammen, is not at present capable of carrying the weight of the electric locomotives.

The length of line over which trolley wire has been erected is about 51 km and of this the 13 km stretch between Christiania and Sandviken is double track construction, making the total length of main line single track electrified about 64 km. To this must be added 30 km of sidings at the 19 stations.

The following particulars apply to the overhead construction, which is in accordance with the specification drawn up by the Norwegian State Railways.

The single catenary system of suspension is used for the trolley wire.

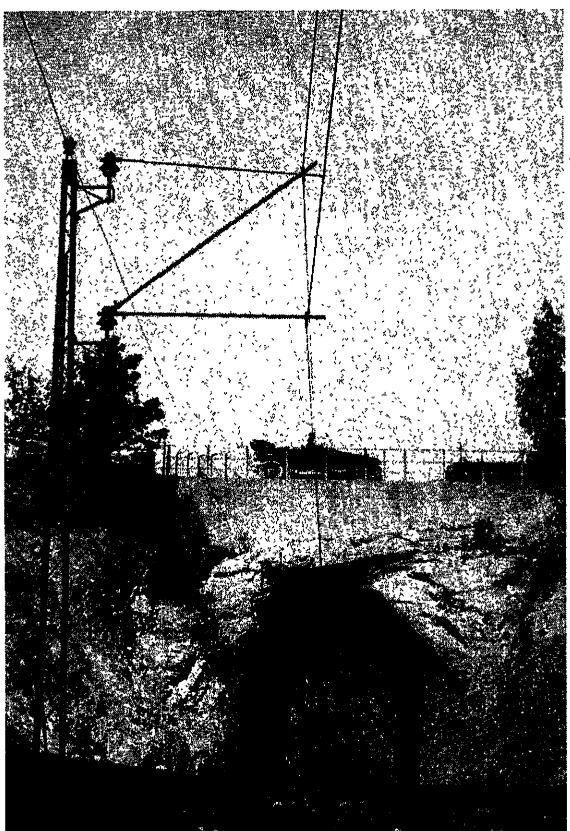


Fig. 2. Standard bracket-arm.

The insulators consist of two parts cemented together. The distance between the supporting poles is 60 m on the straight, with a suitable reduction at curves. The trolley wire is supported, as far as possible, on bracket arms. On stretches where there are more than two tracks the suspension is from cross structures.

The contact wire is supported on the continuously strained system with counter weight and spring straining devices. The height of the trolley wire is on open track $5^1/_2$ m and at stations and road crossings 6 m.

The size of the trolley wire and the design of the equipment has been determined by the following considerations.

Greatest wind pressure 125 kg/m^2.

Temperature limits $-35°$ and $+40°$ C.

Ice loading for the wire 200 + 50 dg/m. (d = the diameter of trolley wire in mm).

Ice loading for iron work 20 % of the weight of the structure.

The cross sectional area of the trolley wire

is on the main line 80 mm^2 copper. On sidings it is 50 mm^2 copper. The catenary or messenger cable has a cross sectional area on the main line of 50 mm^2 and on sidings 40 mm^2.

As regards insulators, it has been specified that these shall on test withstand a mechanical loading three times as great as the maximum load which could be thrown upon them under working conditions. Further they must withstand a sudden change in temperature between 0° and 100° C. The flash over voltage under rain test directed at an angle of 45° on to the insulators is not less than 40,000 volts.

The rails are bonded by copper conductors having a cross sectional area of approximately 50 mm^2 and all structural ironwork and metal parts situated within a distance of 1 m of any live conductor are earthed to the track.

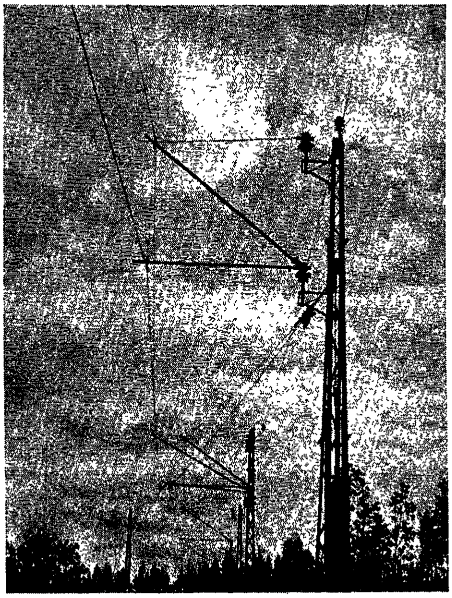


Fig. 3. Standard bracket-arm.

When Asea's representatives in Norway, A/S Per Kure, N.M.D.F. were settling the question of the trolley wire construction they had the advantage of the valuable experience which was obtained by Asea on the Riksgräns Railway, which was electrified in the years 1911 to 1914.

It was found however in calculating out the various parts used in construction on the basis of the stipulated requirements, that most of the details used on the Riksgräns Railway would have to be strengthened or redesigned. A new design was also necessary since here the insulators could not be placed over the centre of the track, as in the case of the Riksgräns Railway, because for some time to come steam trains will be running in addition to

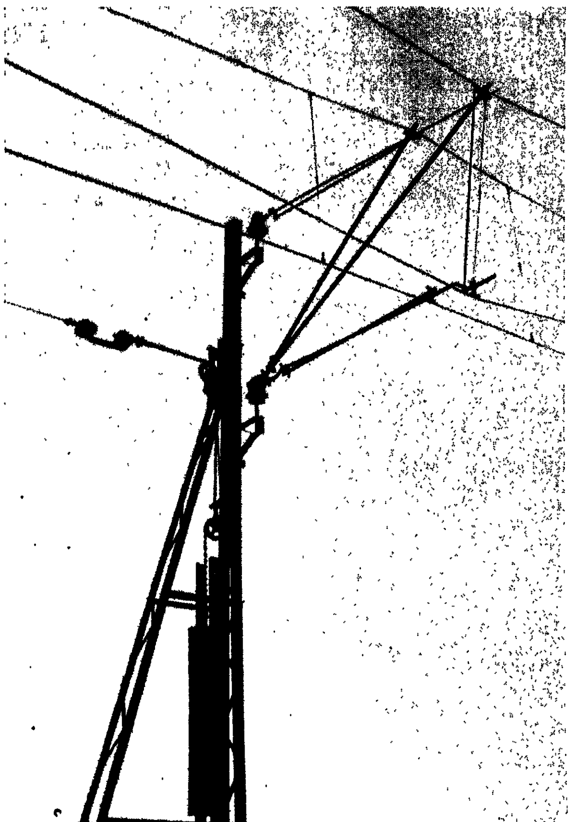


Fig. 4. Counter-weight straining device.

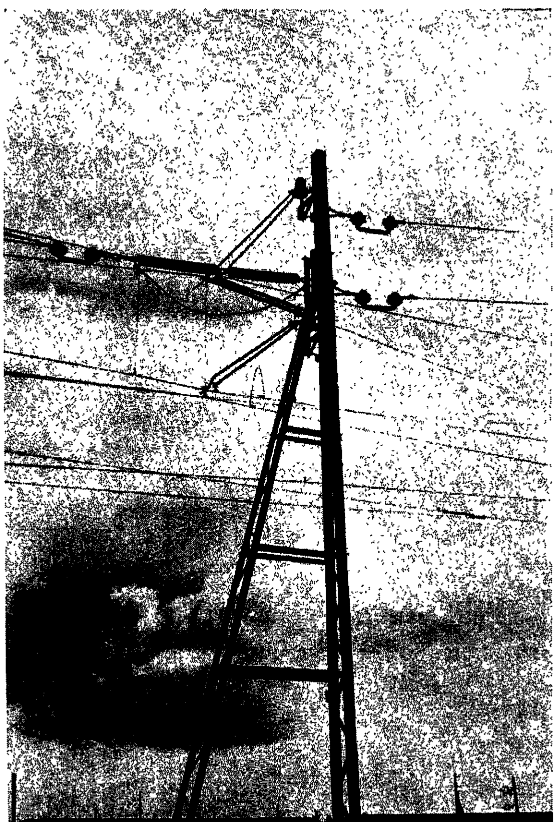


Fig. 5. Spring straining device.

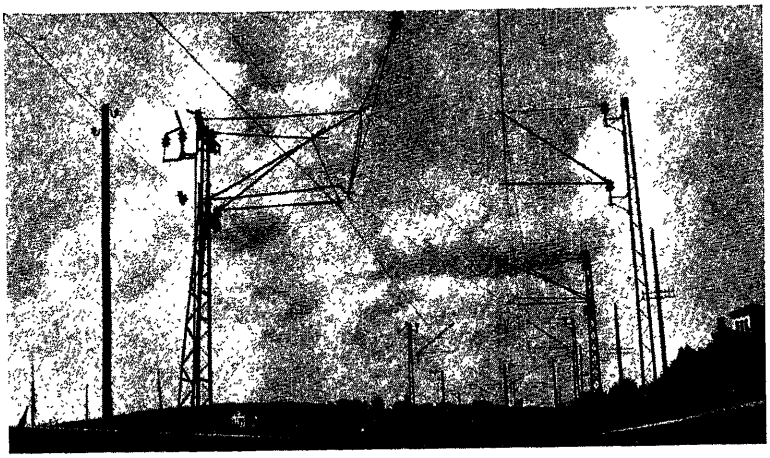


Fig. 6. Section insulator with line switch.

beneath. This requirement is also fulfilled as the push-off of the bracket arm, which is fixed to the bottom insulator, can swing in the vertical plane.

A further requirement for good contact properties is that the sag of the trolley wire must be the least possible, so that the collector bow which is held against the wire by springs need only make small vertical movements. This requirement is met by using catenary suspension. With a normal span of 60 m the trolley wire is supported every 20 m and is strained to an extent corresponding to a sag of 5 cm. Experience has shown that this amount will give satisfactory contact up to running speeds of 90 km per hour.

The method of straining by weights referred to above is shown in fig. 4. On open stretches of track the trolley wire is erected in sections each 1500 m long. At each end of the section a counter weight is placed. In the middle of each section the trolley wire is anchored and accordingly each weight strains a length of 750 m.

A necessary condition of satisfactory working is that the system is installed throughout and that the shortest length of trolley wire in use is furnished with a straining device.

As it would be altogether too expensive to provide all the many short lengths of trolley wire occuring, for example, in station yards etc., and having a length of perhaps only 10 m or so, with weight straining devices, a different arrangement has been used for these, and a spring straining device adopted. On the Drammen Railway all sections of trolley wire under 200 m in length are strained by springs.

By this means, it is true, absolutely constant strain cannot be maintained on the trolley wire

electric trains, and the arrangement would have allowed a deposit of soot to impair the insulation.

The object of the continuously strained system is to obtain great safety against breakage of the overhead wire and to ensure good running contact conditions at all temperatures. With the older systems, when the trolley wire is strained between the ends of each section, the sag of the wire is greater or less as the temperature varies. In the first case especially the contact between the collecting bow and the trolley wire is often particularly unsatisfactory, while at low temperatures dangerous loads are thrown on the poles and other constructional details.

All these disadvantages disappear in the continuously strained system, which has been used on the Drammen Railway and which is shown schematically in fig. 1.

As will be clear from the above diagram the temperature variations of the wire are taken up by weights which keep the tension on the trolley wire practically constant at all temperatures. In order that the line wire can move without hindrance in the longitudional direction, the bracket arms to which the wire is made fast must follow the movements of the wire and they are accordingly pivoted at the ends.

Figs 2 and 3 show the type of bracket arms employed. The bracket arms can swing about the two insulators which are mounted on the poles, one above the other, and whose supporting pins are loose in their brackets. To ensure good contact it is also essential for the trolley wire to be free to move vertically at the points of suspension, so that the locomotive collector bow will pass smoothly

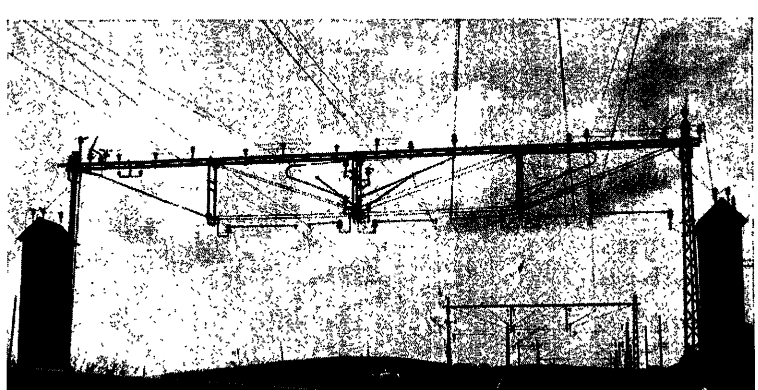


Fig. 7. Supporting structures.

at all temperatures, but experience has shown that the variation in the pull exerted by the spring is not sufficient to affect the contact obtained seriously. Fig. 5 shows a spring straining device having two springs, which is used on lengths of line between 100 and 200 m in length. Lengths of trolley wire such as those in question are anchored at the far end. Fig. 5 also shows how this anchoring is effected.

The sections of trolley wire are connected together through overhead switches as shown in fig. 6. This figure also shows the design of double bracket arm which is used at the ends of sections. Both lengths of trolley wire are here insulated from one another.

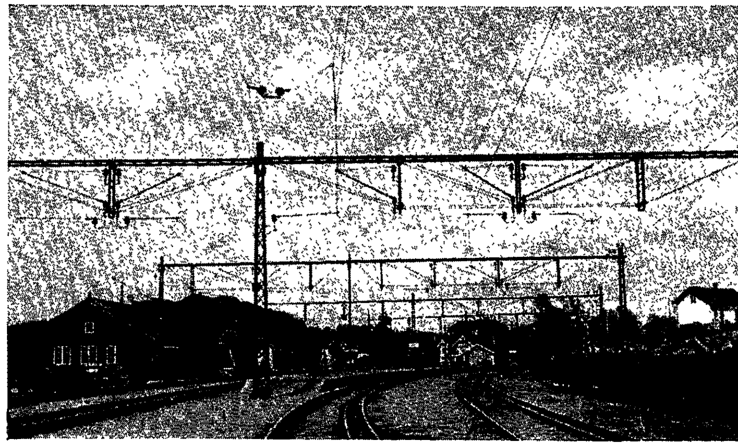


Fig. 8. Supporting structures.

These section insulator bracket arms are so constructed that the two trolley wires are free to move in opposite directions. It will be seen that the overhead construction is comparatively simple and easy along the open sections of the line, but as a station is approached the proposition alters considerably, as is shown in figs. 7 and 8.

Here it is necessary to support trolley wires over a number of parallel tracks. At these points it would hardly do to make use of a pole at each point of support as there would be in some places a forest of poles which would obscure the driver's free view of the signals. In order to interrupt the view at these points as little as possible cross structures have been used to a great extent for supporting the contact wire.

It would occupy too much space to describe the various designs of cross girder construction employed and the method of their application. Fig. 9 is a view showing clearly the difficulties met with in electrifying a section outside Christiania V. Four tracks run here through a narrow neck leading towards Christiania and spread in the direction of Christiania V into a much larger system with a complicated lay-out of points and branch lines.

An auxiliary feeder conductor having a cross sectional area of 50 mm² follows the trolley wire throughout its length and is supported on the trolley wire poles along the whole of the single track sections. This conductor is a part of the arrangement used on the Drammen Railway for neutralising the telephone disturbing effects.

As a protection against electro-magnetic induction in the telephone and telegraph wires track transformers are used. On the single track line from Sandviken to Brageröen a transformer with three windings is installed at every 1500 m. This transformer has a secondary winding for connecting in the track circuit and two primary windings of which one is connected in the trolley wire and the other in the auxiliary conductor.

On double track sections double transformers are installed one for each track with its own trolley wire.

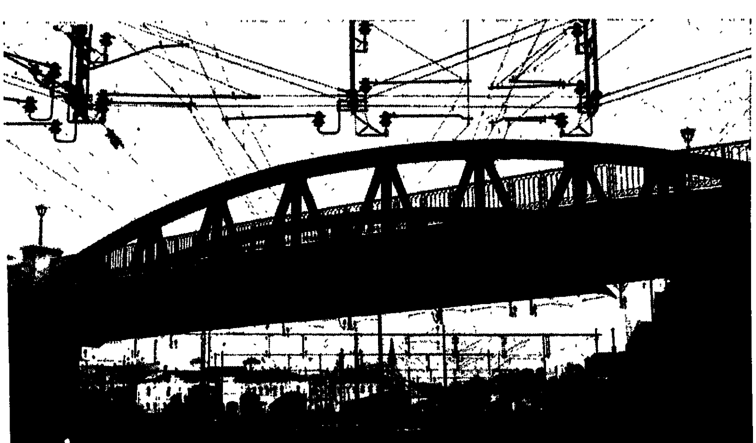


Fig. 9. Arrangement of trolley wires at Christiania V.

The arrangement in principle is in accordance with fig. 10 which shows the connection diagram for part of the single track and double track sections.

The track transformers are contained in kiosks, the appearance of which is shown in fig. 11.

The auxiliary conductor makes it possible to localise faults on the overhead construction and limits the effect of breakdowns to a length of 1500 m. The same object is sought in the arrangement of the switch houses erected at the larger stations, from which any

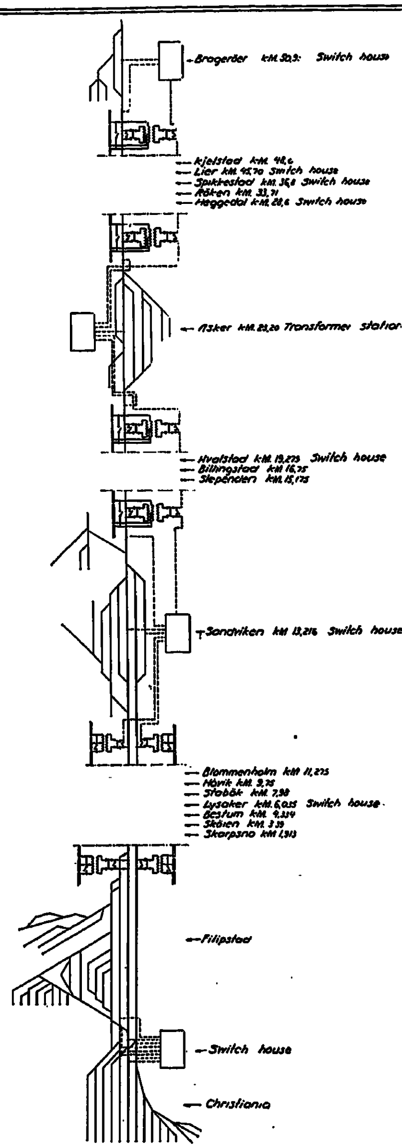


Fig. 10.

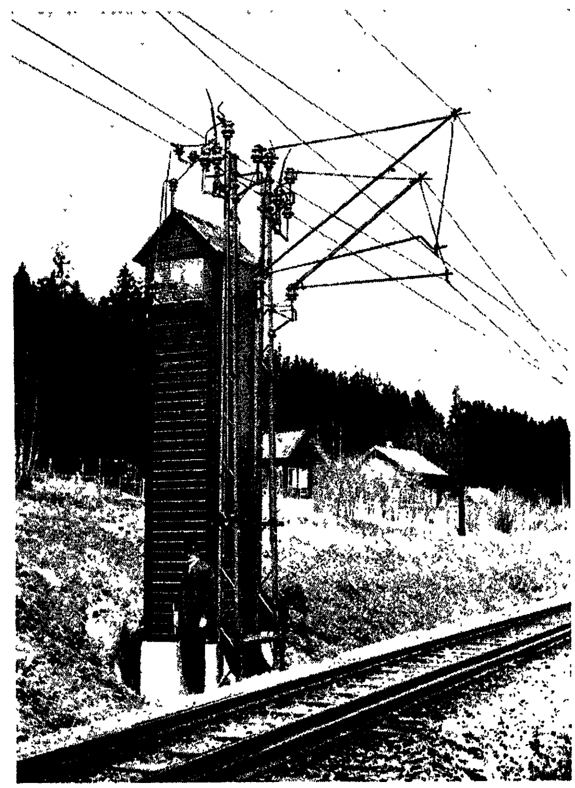


Fig. 11. Track transformer kiosk.

particular track or group of tracks can be connected according to requirements. Fig. 12 shows the switchhouse at Lysaker and fig. 13 the diagram of connections for the arrangement of apparatus in this building.

The rails are bonded with copper bonds throughout. These bonds are arc welded to the side of the rail head, as shown in fig. 14. A portable welding outfit is used consisting of a 15 h.p. Penta motor with D.C. generator, series resistance, and other necessary apparatus, all carried in a railway wagon.

The welding apparatus is provided with an automatic regulating device and works practically without attention. The welding was carried out without interfering with the running of traffic and fig. 15 shows one of the welders at work. As far as railway practice in Scandinavia goes this method of welding the rail bonds has been used for the first time.

An important detail of the equipment, to which particular attention was given on the Drammen

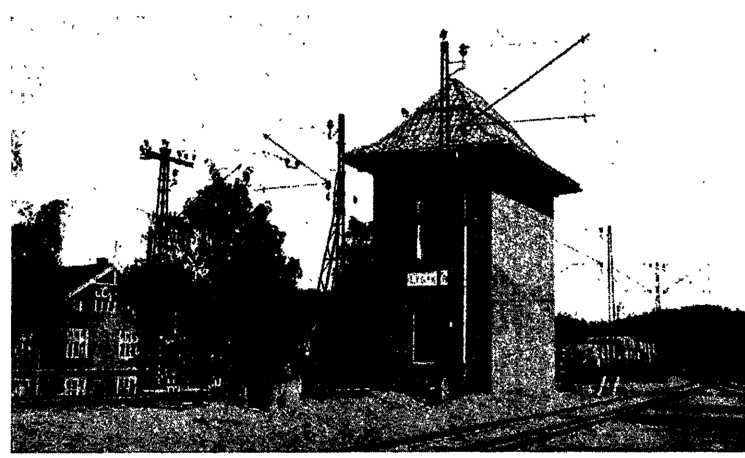


Fig. 12. Switch house at Lysaker station.

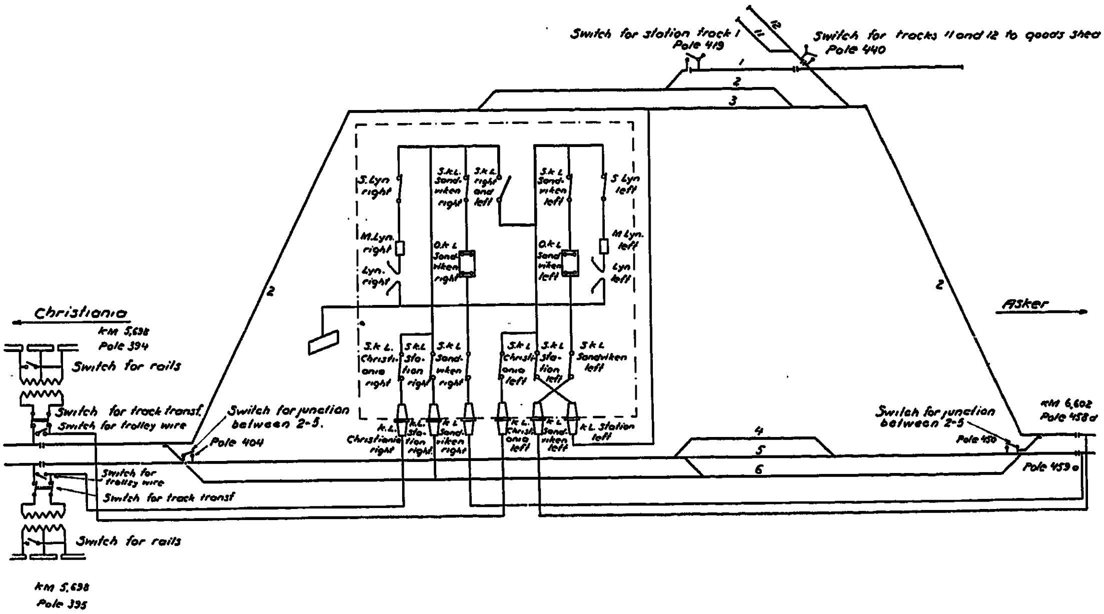


Fig. 13. Diagram of the connections at Lysaker station.

Railway is the type of safety device adopted to prevent accidents through touching the high tension current carrying conductors and structural ironwork. It followed from the question being so long drawn out that definite particulars for the protective devices were not finally settled until the last stage of the work. Here, as in other localities it was desired not to do too much or too little in the way of protection. The Drammen Railway runs partly through a thickly populated district and also partly through country which is very largely visited by sportsmen. About 40 bridges span the railway and for long distances the high road runs parallel to the line. From Sandviken to Brageroen the line runs through deep cuttings in rocky country. In many of these places the live conductors are so near to accessible places that the danger of interference, either accidental or intentional, is very great. The line is, of course, fenced in and on each pole a warning notice is fixed, but at the same time a railway is under an obligation to minimise the possibility of people running themselves into danger, even if they are trespassing. On the other hand the protective devices must not be of excessive size and the maintenance cost of them not be prohibitive.

After careful tests a standard screen consisting of fine mesh iron wire netting has been approved by the local authorities. Figs 16 and

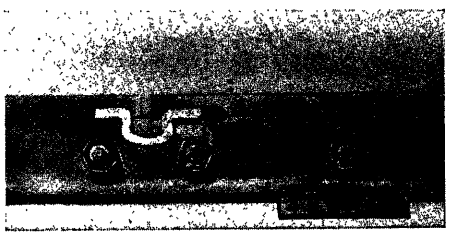


Fig. 14. Rail bond.

Fig. 15. Welder at work.

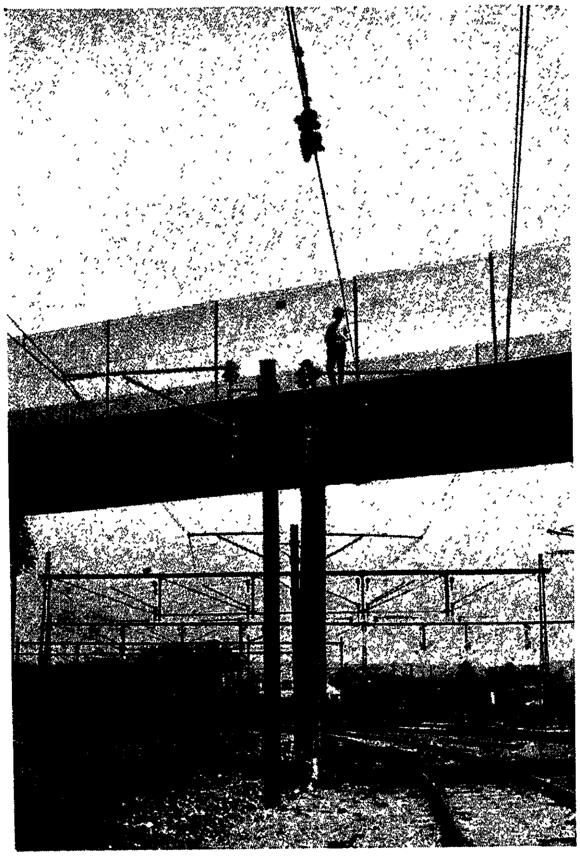


Fig. 16. Protecting screen at bridge.

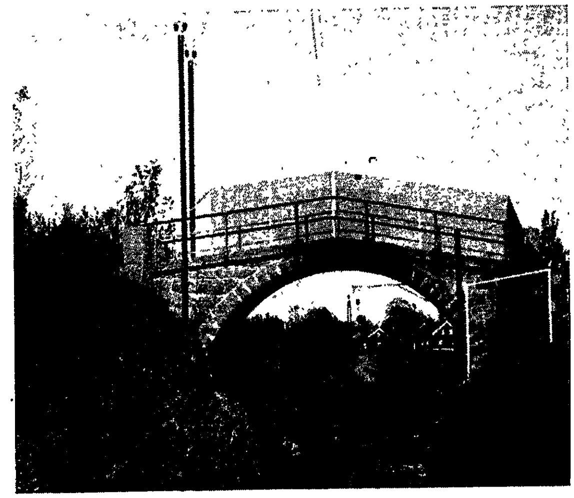


Fig. 17. Protecting screen at overbridge.

17 show how this net is used where bridges cross over the line when the trolley wire lies less than one metre from the footway of the bridge. The photograph of the bridge shown in fig. 17 shows a protecting screen in the form of a fence and also the method of taking the auxiliary feeder conductor over the bridge.

Fig. 18 shows a protecting net mounted upon a pole in such a way as to prevent persons who have climbed over the railway fencing coming by any means into contact with the lower insulator, which supports the bracket arm and which carries the full voltage of 15,000.

The whole overhead system has now been in use for a couple of years and during this time no trouble worthy of note has arisen.

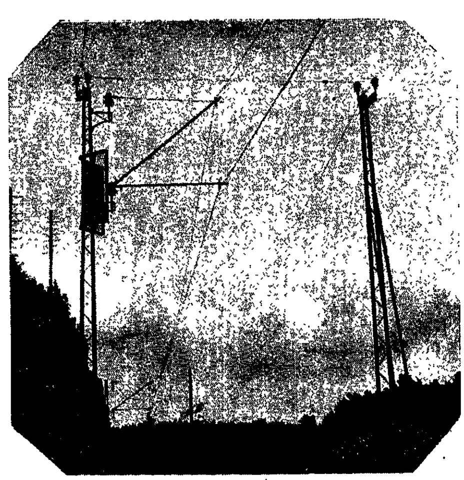
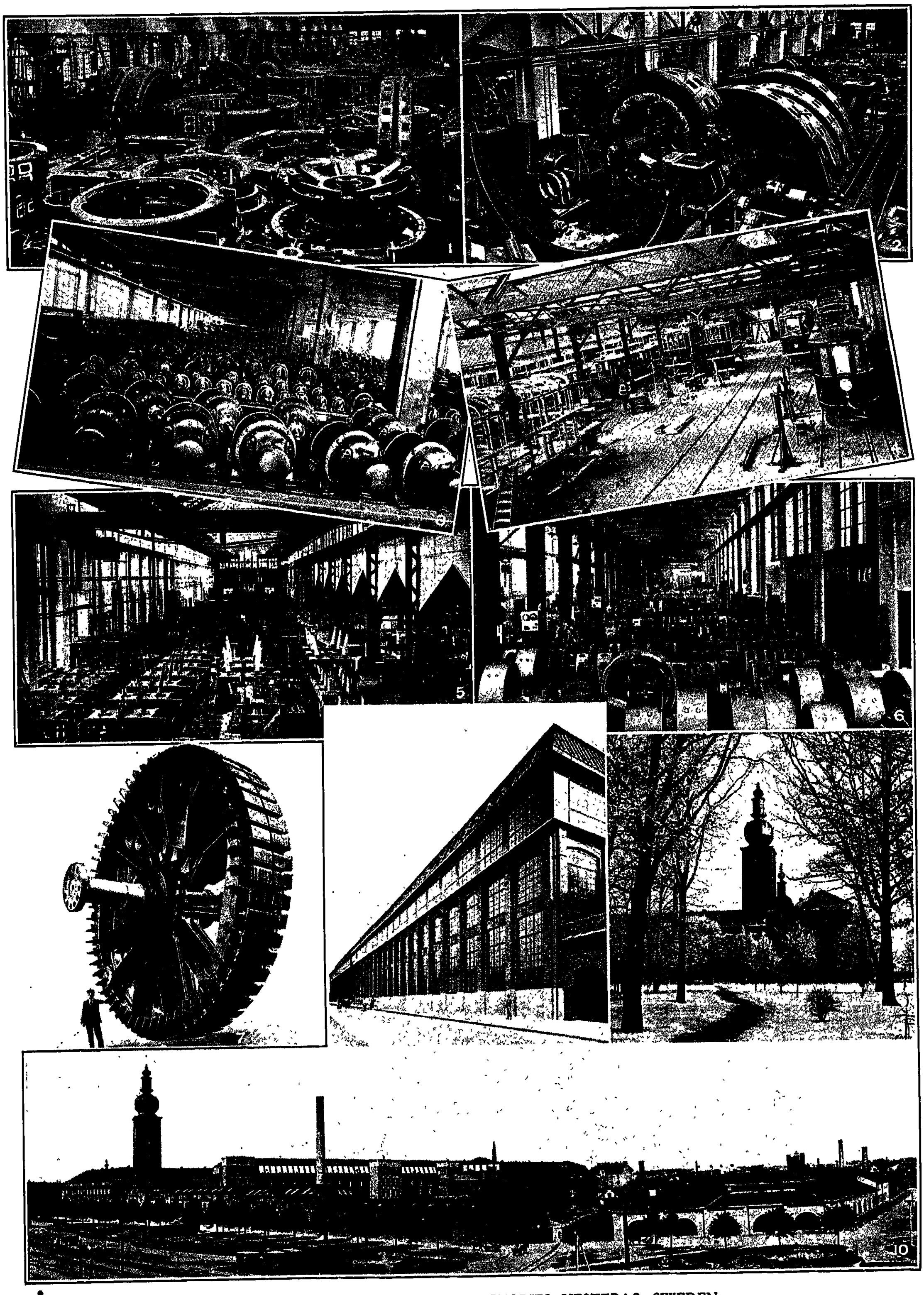


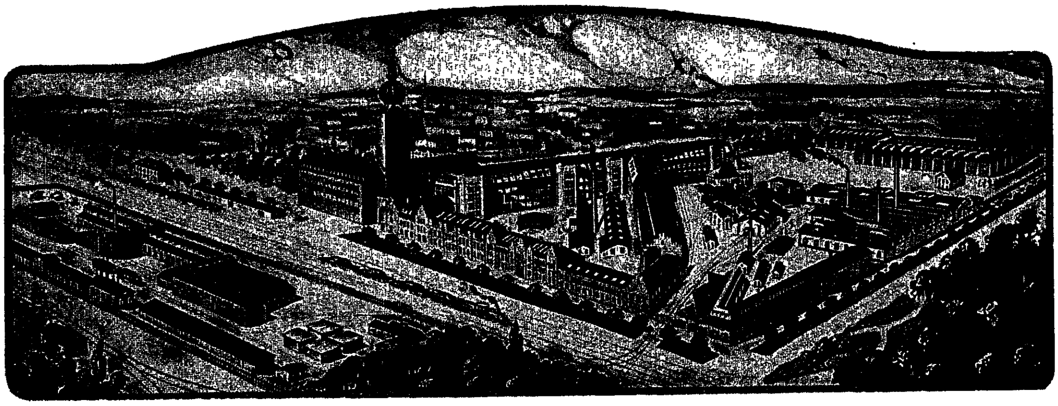
Fig. 18. Shield pattern screen.

CURRENT ILLUSTRATIONS.



SOME PICTURES FROM ASEA'S FACTORIES, VESTERAS, SWEDEN.

1) Workshop for large machines. 2) Some large machines under construction. 3) Testing room for small motors. 4) Manufacturing railway and tramcar bodies. 5) Manufacturing of large oilswitches. 6) Workshop for small and medium sized machines. 7) Rotor of a modern 12,000 kVA three-phase generator. 8) The »Mimer» works for small and medium sized machines. 9) The head office. 10) The head office, works for small and medium sized machines as well as foundries.



Asea's head office and works in Vesteras, Sweden.

ALLMANNA SVENSKA ELEKTRISKA A.B.

Head office: VESTERAS, SWEDEN
Works: Vesteras and Ludvika
Telegrams: Asea, Vesteras

SWEDISH GENERAL ELECTRIC LTD

5, CHANCERY LANE, LONDON
Works: Fulbourne Rd., Walthamstow
Telegrams: Autosyncro, Fleet, London

OFFICES, ASSOCIATED COMPANIES AND AGENTS:

ARGENTINA
Compañia Sudamericana SKF, Buenos Aires. Victoria 502.

AUSTRALIA
Unbehaun & Johnstone, Ltd., Perth, W. A. 383/387 Murray Street.
Unbehaun & Johnstone, Ltd., Adelaide, 100 Currie Street.
Thomas Bros. Pty, Ltd., Melbourne. 201/203 William Street.
Australectric, Ltd., Sydney, Wireless House, 97 Clarence Street.
Intercolonial Boring Co. Ltd., Brisbane, 450/460 Ann Street.

BELGIUM
Société Belge d'Electricité Asea, Bruxelles, 21 Rue Grétry.

BOLIVIA
Graham, Rowe & Co., Oruro, Alianza 581.

BRAZIL
Haupt & Co., Rio de Janeiro, Rua São Pedro 50
São Paulo, Rua Boa Vista 46.
Porto Alegre, Rua 15 de Novembre 16.

CANADA
Swedish General Electric Ltd., Toronto, Ont., 107 Duke Street.

CHILE
Graham, Rowe & Co., Valparaiso, Cochrane 825.
Santiago, Bandera 267—275.
Antofagasta, San Martin 362.

CHINA
Henry J. Moysey, Shanghai, Peking Road 64.
J. Whittall & Company Ltd, Tientsin. 15 Victoria Terrace.

DENMARK
Elektricitets Aktieselskabet Asea, Copenhagen K, Bredgade 45.

ESTHONIA
Linke, Martinson & Co., Reval, Kinga tän 10.

FINLAND
Allmänna Elektriska Aktiebolaget i Finland. Helsingfors, Citypassagen.

FRANCE
Société Française d'Electricité Asea, Paris. Boulevard Haussmann 114.

HOLLAND
Groeneveld, van der Poll & Co., Amsterdam, De Ruijterkade 41, 42.

INDIA
Ewing & Co. Ltd., Calcutta. 4, Clive Row.
The Consolidated Mills Supplies Ltd., Bombay. Yusuf Building, Churchgate Street, Fort.

JAPAN
Gadelius & Co., Tokyo, 41, Akashi-cho Tsukiji.
Kobe, 58 B, Naniwa machi.
Dairen, 45, Yu-ku, Satsumacho.

NEW ZEALAND
A. S. Paterson & Co. Ltd., Wellington, 12 Cuba Street.

NORWAY
A/S Per Kure, Norsk Motor- og Dynamofabrik, Christiania, Universitetsgate 24.

PERU
Graham, Rowe & Co., Lima. Villalta 282.

PORTUGAL
Jayme da Costa L:tda, Lisbon, 16 Rua dos Correeiros 26.

RUSSIA
Acea, Leningrad, Uliza Gogolja 7.

SOUTH-AFRICA
Reunert & Lenz, Johannesburg. Consolidated Buildings.

SPAIN
Sociedad Española de Electricidad Asea, Madrid, Calle Montalban 13.

BESIDES REPRESENTATIVES IN:

GREECE. LATVIA. MEXICO.

Vesteras 192[illegible], Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

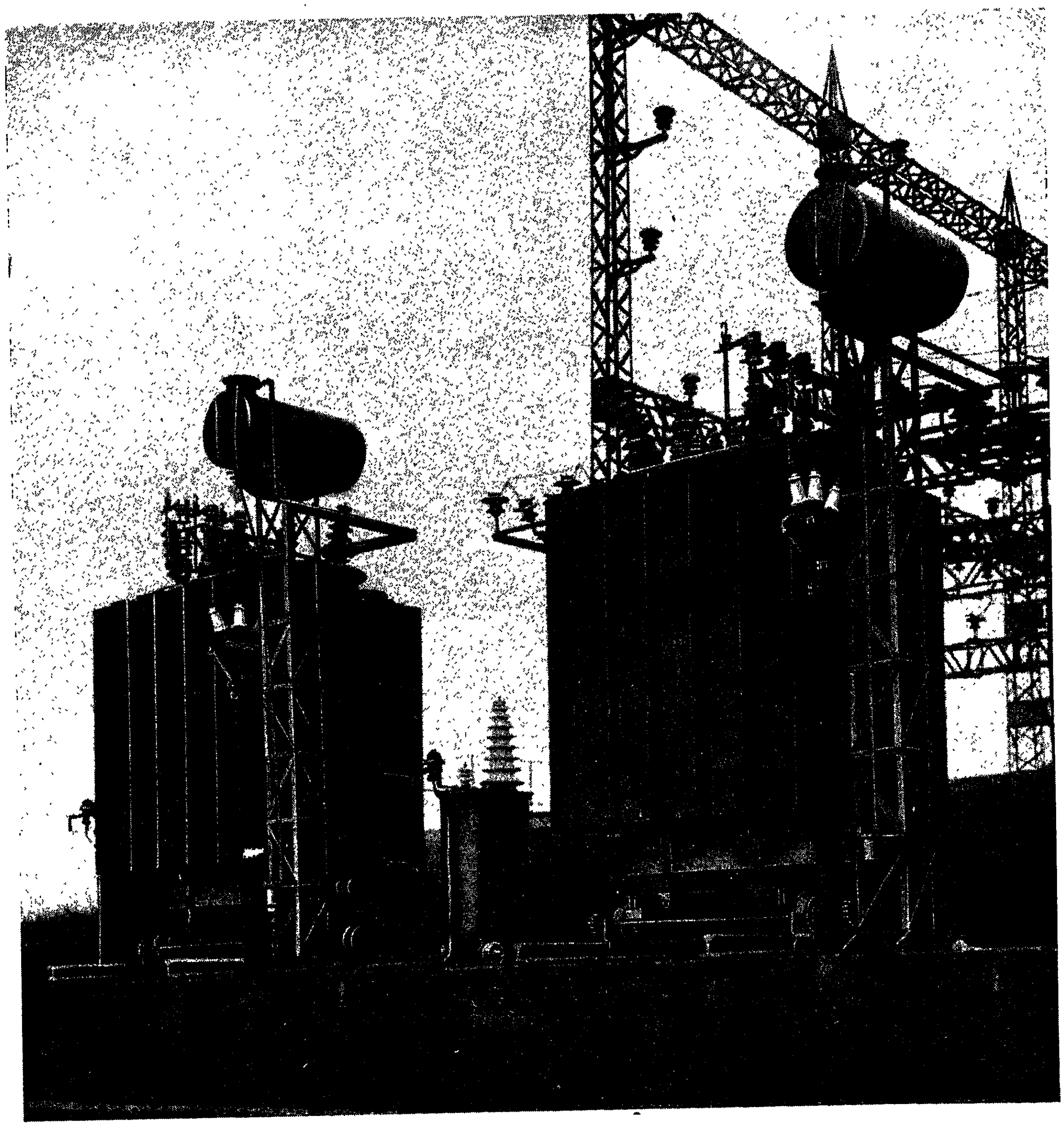
ALLMANNA SVENSKA
ELEKTRISKA A.B.
VESTERAS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

NOV.-DEC.

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesteras, Sweden.
Permission is given to reprint articles or extracts from this journal,
on condition that the name — Asea-Journal — is clearly stated.

1924

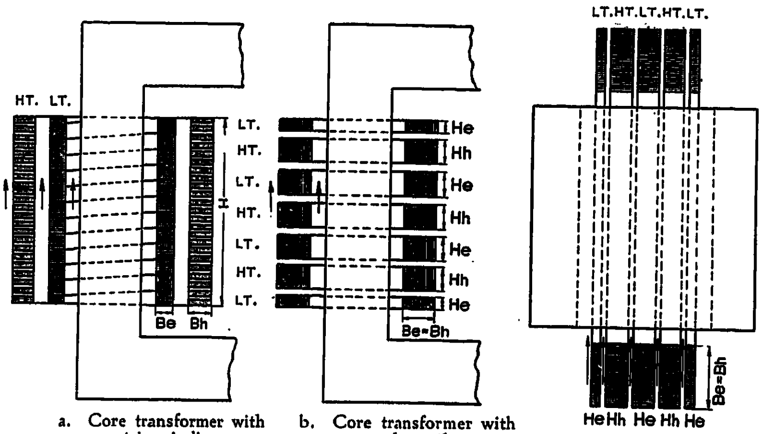


Asea three-phase transformers for outdoor installation, each 2,500 kVA, 6,000/50,000 volts. Belgium.

ELECTRIC FURNACE TRANSFORMERS.

Introduction.

The most important characteristics of the electrical equipment of furnaces are dependability, great resistance to damage by rough usage, and suitability of electrical qualities. A »shut down» caused by the failure of the electrical equipment always means economic loss and sometimes entails the destruction of parts of the furnace. The electrical plant must be designed with special regard to furnace conditions, and also with due consideration to the men working it, who are used to handling heavy things, and are consequently not usually very careful. Lastly, uninterrupted and economical operation of the furnace is required and this demands thorough interchangeability between all parts of the electrical plant. The principles on which Asea's present-day furnace transformers are constructed, and the extent to which they meet the special requirements mentioned above will be shown in the following.



a. Core transformer with concentric windings. b. Core transformer with pancake coils. c. Shell transformer.

Fig. 1. Cross section through core and shell type transformers through the axis of the windings. The arrows give generally the direction taken by the cooling oil.

Comparison between Shell & Core Types.

The chief points of difference between a furnace transformer and an ordinary power transformer are that a transformer for furnace work is dimensioned for a secondary current which is very high in comparison with the output; is usually provided with extra tappings on the primary winding for varying the secondary voltage in the ratio of 1:1.25 or 1:3; and finally is often designed to withstand direct short circuits on the secondary side as well as heavy mechanical stresses of various kinds. For power transformers the core type has in our experience been found most suitable, and at the present time practically all power transformers are made in this way. This type, however, has certain drawbacks when considered in relation to the special requirements of furnace transformers. For sizes above 100 kVA these last are accordingly always constructed of the shell type.

It is not intended to consider here the fundamental differences between core and shell type transformers, we only wish to point out the properties which determine the relative fields of use for the two types in the present case. We accordingly refer to fig. 1. The windings on a core transformer, in order to obtain good cooling, suitable insulation to core and between windings, and small stray losses in the conductors, must be executed with small radial breadth in proportion to their axial length. Such coils are accordingly long and narrow and with few turns per coil; when they are made for heavy currents they must necessarily be divided into a large number of parallel conductors on account of eddy current losses. The windings in a shell transformer must, in order to obtain the same good characteristics, be made with great radial breadth in proportion to their axial length. The coils in a shell transformer for heavy currents can therefore be furnished with massive copper conductors "wound" on edge so as to give great mechanical stability, without fear of the eddy current losses becoming too high. The high tension windings, *i. e.* those which carry a considerably smaller current, are wound on the same principle for both large core and shell transformers, of copper strip wound flat in spiral coils. From a mechanical standpoint accordingly the difference between the windings in core and shell transformers is that in the former they are less stable mechanically, and more difficult to manufacture. The terminal leads in addition must be fixed to the many conductors of the winding by cable clamps and bolts, while in shell transformers these leads can be sweated direct to the coils which are themselves massive copper conductors and thus make a continuous whole with the leads.

The arrangement of extra tappings on core type transformers always entails special consideration in order that they may not give rise to undesirable effects. In particular when tappings are provided so that a considerable part of the windings are disconnected, special arrangements

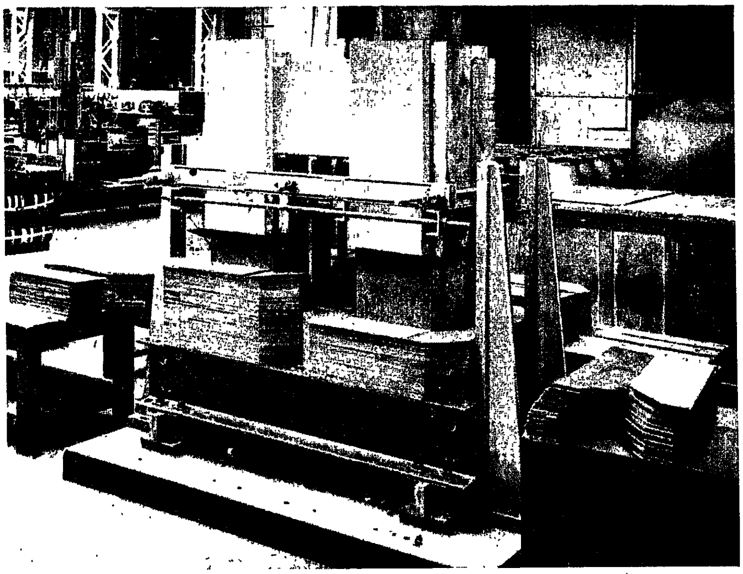


Fig. 2. Assembling core plates on a shell transformer.

must be adopted, so that the high and low tension windings shall not become magnetically unbalanced, and large eddy current losses and considerably increased reactance occur in the transformer when the tappings are changed. Where many regulating steps are required and when more than 30 % of the winding is to be disconnected, these difficulties become very great in windings for over 1,000 volts, and it is accordingly very difficult to use core type transformers at all in such cases for furnace work. In a shell type transformer, however, no difficulties whatever are met with in providing extra tappings by which 60 or 70 % or more of the winding is disconnected. The only point demanding care is that the tappings are so arranged that the reactances of the parallel connected low tension coils are as far as possible the same. The advantages of the shell type transformer over the core type transformer, as regards the bringing out of extra tappings for large percentage differences, are accordingly very great, and constitute the chief reason for the use of shell type transformers for furnace work.

As shell type transformers are always constructed with rectangular coils and core type transformers with circular coils, and as in a shell type transformer the coils of the high and low tension windings are distributed alternately in the axial direction while the windings in the core type can be made concentric, the stresses which normally occur in the axial direction in a shell type transformer are very much greater than the corresponding stresses in a core type transformer, especially if the last is not furnished with extra tappings or has windings which are magnetically well balanced. The stresses occuring in a radial direction are smaller in the shell type transformer, but the core type transformer has the advantage that these radial stresses on account of the circular form of the coils are taken up by the copper in the winding itself, while the rectangular coils of the shell type transformer must be very strongley supported in order that they will not be deformed when short circuits occur. It may be said in parenthesis that the radial stresses in a shell type transformer are not of such great importance, since on account of the construction of the iron core they are neutralised to a certain extent by the attraction of the core. The mechanical stresses which are dangerous to the windings in a shell type transformer are accordingly always considerably larger than in a core type transformer with concentric windings, and in order to obtain a construction entirely satisfactory in use it is necessary to provide winding supports of a specially heavy nature in shell type transformers. There is, however, no particular constructional difficulty in making these winding supports sufficiently safe, and accordingly the drawbacks due to the greater mechanical stresses in a shell type transformer are not so great. They must, however, partly on this account be made heavier and more massive than corresponding core types, and they are accordingly also somewhat more expensive to manufacture.

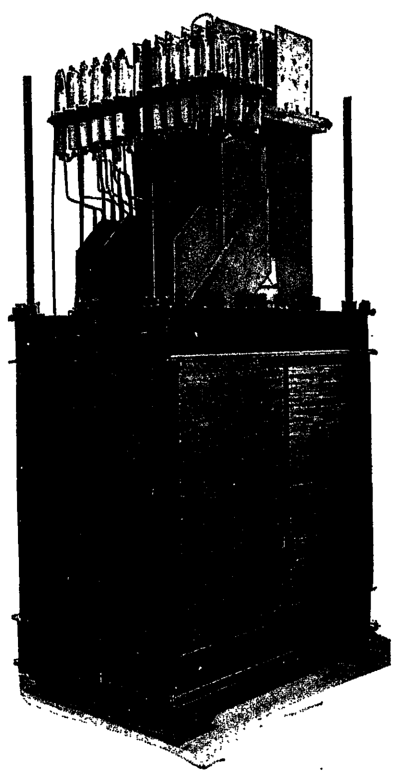


Fig. 3. 4,000 kVA furnace transformer for 10,000/60—100 volts, 50 cycles, Scott connected. Transformer arranged with overlapping core joints.

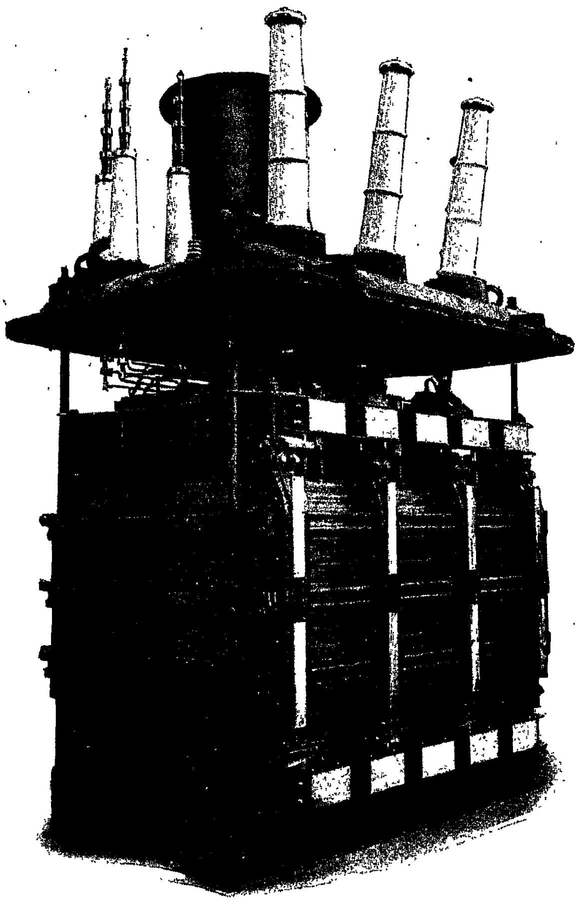


Fig. 4. 3,000 kVA power transformer for 72,500/40,000 volts, 50 cycles. Transformer with butt jointed core.

Constructional Details of Shell Type Transformers.

During the long period in which we have manufactured shell type transformers, we have had the opportunity of testing many different principles of construction which have proved to be more or less dependable in service and suitable for their work. This long experience has been brought to bear on the design of our present type of shell transformer, and in the following some of the principal details of our present construction will be dealt with.

The Core.

The cores are always constructed with overlapping joints (see fig. 2) and without any bolts traversing the core plates themselves. The advantages of this are that the losses in the iron are the smallest possible, that the transformers work silently, and lastly that the stacks of core plates themselves act as a mechanical support for the windings. By heavy end supports which are placed over and under the core plates and drawn together by stay bolts outside the core, (See fig. 3) the core is tightly pressed together and this pressure and the friction between respective core plates in the joints is sufficient to take up the mechanical stresses from the coils. In this way no supports are required for holding the core together in the direction of the plane of the core plates. When the core is made with "butt" joints instead of with interleaved joints, such supports are absolutely necessary for taking up the mechanical stresses from the coils, and the construction is accordingly much more heavy and clumsy. (Compare the illustrations in figs. 3 and 4 of which fig. 3 shows a 4,000 kVA smelting furnace transformer with overlapping joints and fig. 4 a 3,000 kVA transformer with butt joints. In general it is thought that butt joints are an advantage in shell type transformers on account of the greater ease in erecting and dismantling. According to our experience this is not the case. The erection of a transformer with butt joints, reckoning the time for placing the different stacks of core plates in position, takes at least as long as the erection of a transformer with interleaved joints, and the dismantling of a transformer in a case where one or other of the coils is defective is practically as simple. On a transformer with butt joints it is not necessary to dismantle the whole core for repairing some part of the winding, but on transformers with interleaved joints only one side need be loosened out, and the defective coils removed from the remaining part.

Windings.

The windings are built up as before described, the high tension coils being of spiral wound strip and the low tension coils of massive flat copper bars. The construction of the former is in accordance with fig. 5. The coils are wound of copper strip on the flat and this construction affords the advantage that the coils are very compact and strong mechanically. The conductors themselves are cotton covered and for high voltages a combined paper and cotton covering is used. In addition presspahn or paper is introduced between turns to increase the strength of the insulation. As the conductors are wound

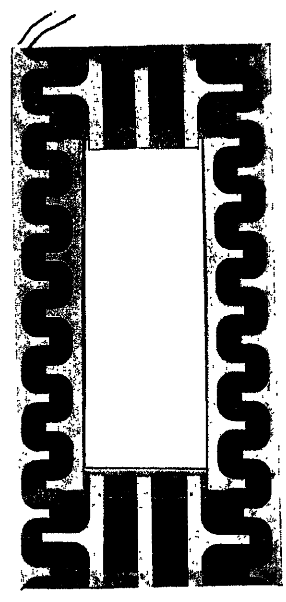


Fig. 5. High tension coil for 1,000 kVA furnace transformer. 12,500/50—180 volts, 25 cycles.

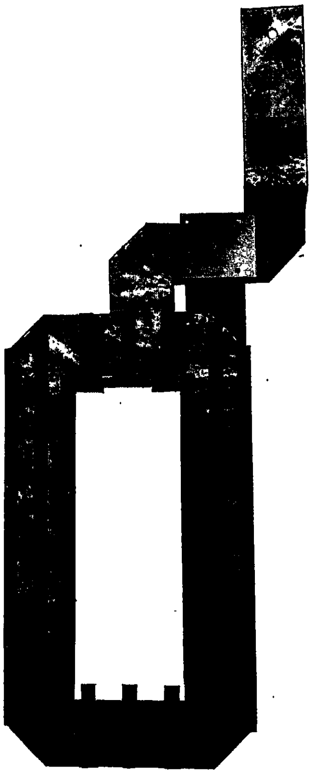


Fig. 6. Low tension coil for 1,000 kVA furnace transformer. 12,500/50—180 volts, 25 cycles.

as above and with presspahn placed between them there is practically no possibility of the insulation between the conductors breaking down in use. Such windings are accordingly particularly free from breakdown troubles. The safety of the coils in use is also increased by impregnating all the coils in a vacuum with oil resisting varnish so that the risk of the insulating material absorbing moisture is greatly decreased whilst the coils are rendered very rigid. No extra strengthening of the insulation on the conductors near the terminals is furnished on furnace transformers, but insulation of the same strong character is used throughout in all parts of the windings, this having shown itself to be the best and safest principle when it is necessary to protect against abnormal pressure rises. The low tension windings are always constructed of flat copper bars welded together and are left bare and not provided with any insulation round the conductor itself, see fig. 6. These coils are insulated from one another and from the core and high tension windings by the insertion of presspahn and wooden strips.

Insulation.

As regards the insulation between the respective windings and between the windings and the core, it is only necessary that this shall be dimensioned in a suitable manner to meet the electrical requirements. The insulation must also have very good mechanical characteristics so that it will not shrink or settle after being some time in use, also that the mechanical pressure exerted on the windings when the transformer is fully assembled will not decrease with time, allowing the coils to become loose. If the coils can move in this way the stresses set up on a short circuit are much more dangerous than if the coils are heavily pressed the whole time.

In order to obtain insulation which corresponds to the requirements as regards mechanical windings. we now always employ presspahn, fibre, baked etc. materials which besides being strong do not shrink or warp after being in use for some time. The manner in which the insulating is carried out is shown in fig. 5. Round the long sides of the coils are laid pressed U-shaped strips of presspahn, which are so formed that not only is a long leakage path from the winding to iron obtained, but also as large a part as possible of the winding is open, giving a large area for dissipation of heat between the conductors and the oil in the oil channels, so that the windings are effectively cooled, and the copper can be fully utilised without fear of any part of the winding reaching a temperature dangerous to the transformer. Between respective coils are laid, in addition, presspahn guards alternating with the oil channels and depending on the working voltage and guaranteed test pressure.

For taking up the mechanical pressure and ensuring that the coils will be immovable, even under the pressures resulting in the event of short circuits, heavy wood strips are placed between the core and the coils after the transformer core and windings are erected and the end supports assembled. The free coil ends over and under the core are forced together by special press-screws (see fig. 14) acting on heavy plates.

Additional Tappings.

In arranging extra tappings for regulating the secondary voltage it is in general only necessary

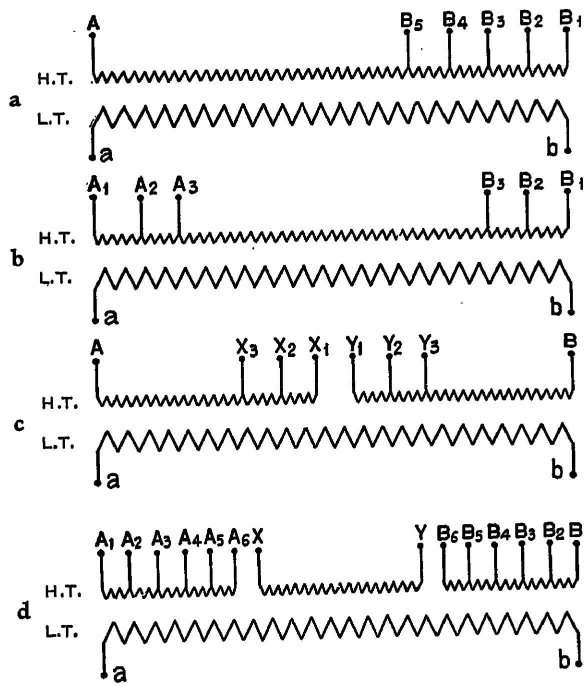


Fig. 7. Arrangement of tappings for furnace transformers.

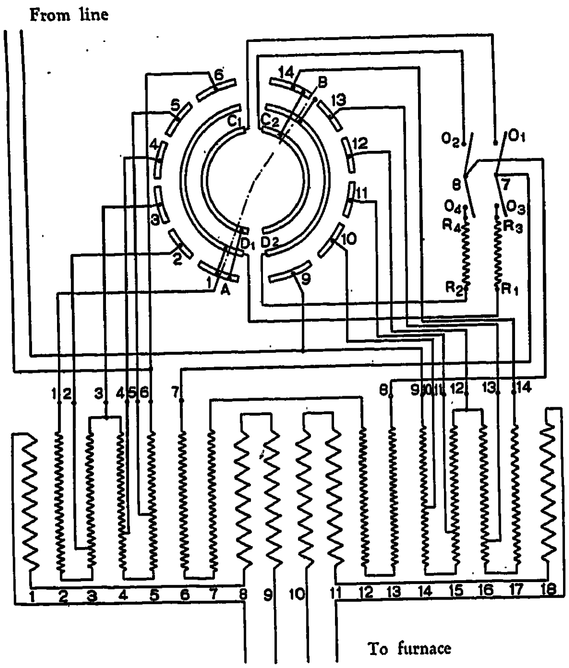


Fig. 8. Connections of a transformer and winding coupler for large pressure variation.

to consider three things. In the first place of course they should be so arranged as to give the required regulation. They should be placed so that they do not endanger safe operation; so that, as far as possible, the same reactance is maintained in secondary coils which may be connected in parallel; and so that no voltage appreciably higher than the normal can exist, during working, across any parts of the transformer windings.

Our additional tappings are always made with copper strip which is riveted and soldered direct to the conductors themselves, carefully insulated in the coils and brought out through the oil channel between the respective coils in flat bakelite tubes. By this arrangement the risk of breakdown by a failure at the tappings is reduced to a minimum. To maintain the same reactance in the secondary coils the tappings must as far as possible be placed symmetrically with regard to the respective windings. This is, however, not absolutely necessary since in a suitably arranged furnace installation the parallel connection of the respective secondary coils is effected at the furnace itself. To the reactance of each coil is therefore added the reactance of the leads between the transformer and the furnace. As the reactance of these leads is in most cases two or three times greater than that of the coils themselves a relatively large difference in the reactance of the transformer coils has a small effect on the division of the current in different coils during normal operation. In this connection it should be pointed out that when carrying out a short-circuit test on a furnace transformer with many parallel connected coils in order to determine the short-circuit voltage and copper losses, the secondary coils should always be connected in series so that the same current passes through all the coils, since with parallel connection there is no means of ascertaining what division of current is actually being obtained. Our guarantees regarding transformer copper losses and reactance are always given on the assumption that a short circuited test for their determination will be carried out in the above manner. If the extra tappings for varying the secondary voltage are placed at the end of the high tension winding, as shown in fig. 7a and b, then when the full voltage is applied across terminals A and B_5 or across A_3 & B_3 a higher voltage will be obtained between terminals A & B_1 or A_1 & B_1 respectively. In cases where the regulation amounts to a maximum of not more than 30 to 40 % (the highest voltage being accordingly 30 to 40 % greater than the working voltage) this is not of great importance since the test pressure is always twice the working voltage + 10,000 volts and furnace transformers are not normally constructed for higher working voltages than 20 kV. If however the alteration is greater, the ratio being say 2 or 3 and above it will be seen that the arrangement in fig. 7a and b will give rise to dangerous pressures, especially if the transformer is not designed for

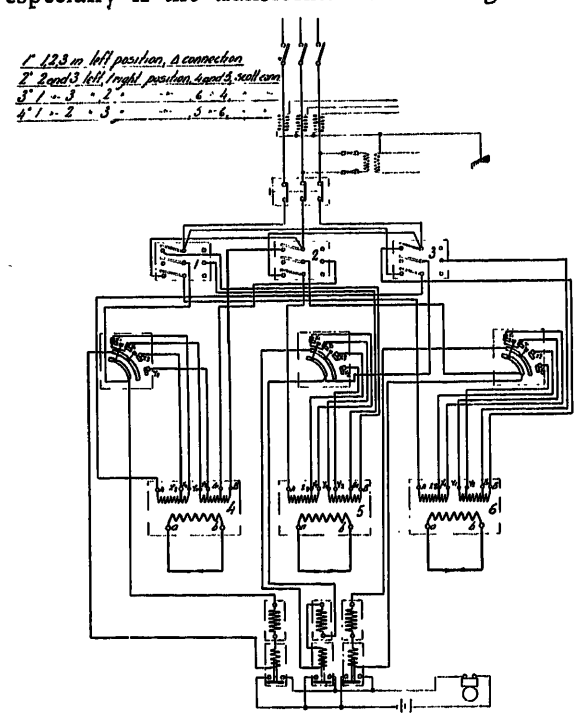


Fig. 9. Scheme for changing from delta to Scott connection for three furnace transformers.

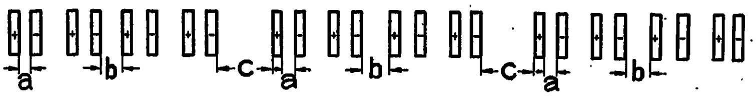
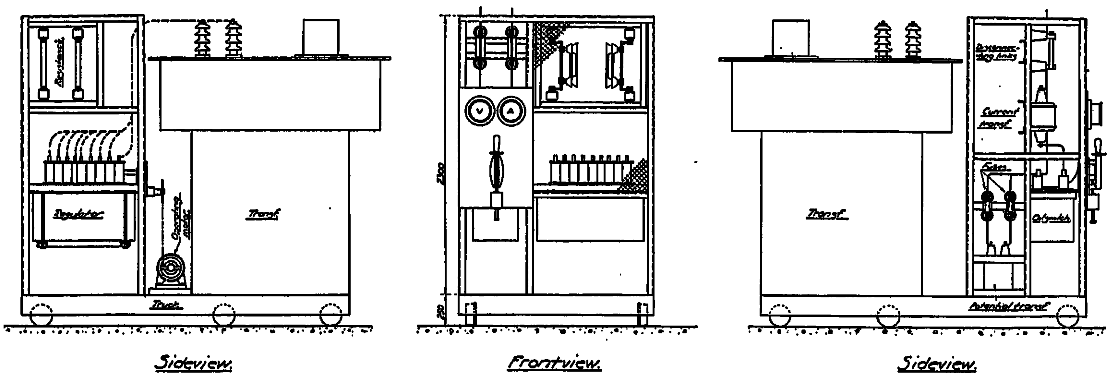


Fig. 10. Furnace leads.

a higher test pressure than twice the working voltage + 10,000 volts. In such cases the tappings are arranged in a special way for reducing the highest voltages which can occur. This is commonly managed by dividing the HT winding into two parts (fig. 7 c) or more (fig. 7 d) these parts being electrically separated and connection between them being effected outside the transformer by extra terminals. At the outer points (A—B) of the winding there thus always exists the normal working voltage. The highest pressure difference arising is thus equal to the working voltage if the ratio of the change is less than 1:2 or the working voltage multiplied by half the change if this is greater than two. If the winding is further divided the reduction in voltage is still greater. As an example of the way in which the connections can be made in order to reduce the highest pressure difference we may refer to the scheme shown in figs. 7d and 8. (Fig. 8 shows how the transformer and the winding coupler belonging to it are connected together in such a case). These apply to a single phase transformer of 1,000 kVA 12,500/50—180 volts with additional tappings on the HT side for regulating the secondary voltage between the voltages given above in equal steps each of 10 %. If this transformer were arranged, as in fig. 7a, then a secondary voltage of 180 volts would mean a maximum pressure of 45,000 volts being maintained on the HT windings. If the HT windings are in two parts as in fig. 7c the maximum pressure would be 32,500 volts with 180 volts on the secondary side. As actually constructed the maximum pressure has been reduced to 20,000 volts. This transformer is accordingly built as a 20 kV transformer as regards insulation although for use on a working voltage of 12,500 volts only.

Systems of Pressure Regulation.

For regulating the voltage it has been previously said that extra tappings are arranged on the high tension side of the transformer for reconnection outside the transformer. The reconnecting can be done with the transformer disconnected from the supply by means of ordinary knife switches or other arrangements or during working by the help of our winding coupler type UR, which was developed a very long time ago. The last arrangement, *i. e.* a transformer with extra tappings on the high tension winding combined with a coupler of type UR appears to us to be the most suitable for furnace work, as on account of its simplicity it is very dependable in action and easily operated by hand. Another system which we have made use of several times in the past is to use two transformers both without extra tappings, one (the main transformer) furnished for the mean voltage required by the furnace and the other (the booster transformer)



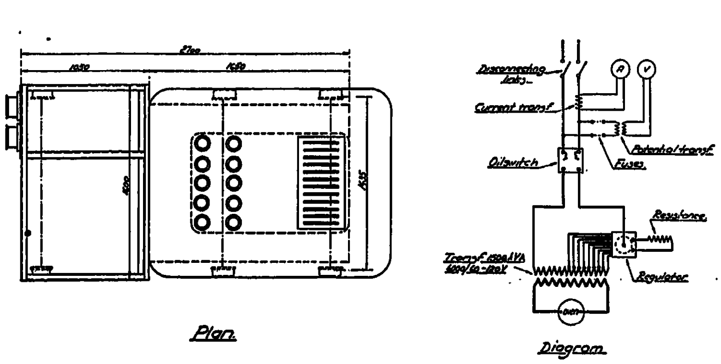


Fig. 11. Arrangement of portable furnace equipment.

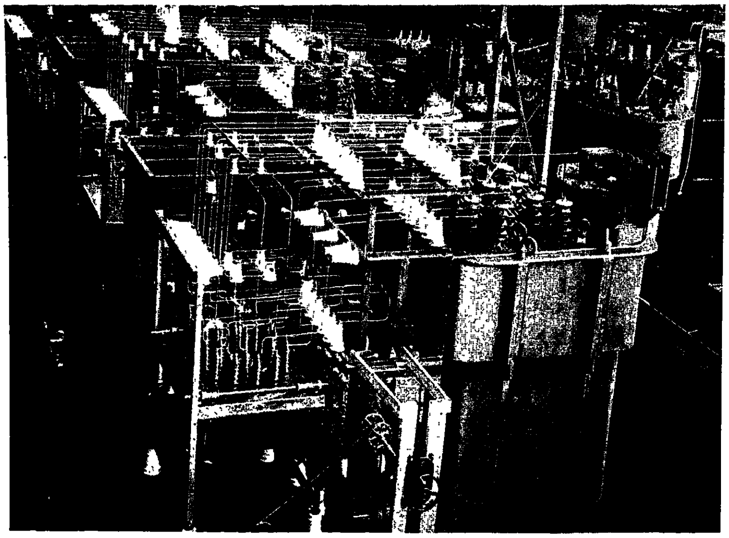


Fig. 12. Portable electric equipment for 1,000 kVA, single phase 12,500/50—180 volts, 25 cycles.

furnished for a voltage equal to the required pressure step and connected in series with the main transformer on the secondary side. By connecting the booster transformer voltage in series or in opposition to that of the main transformer and by short circuiting its high tension winding three regulating steps are obtained. This system besides complicating the layout of the plant also has the disadvantage that it can only be arranged for three regulating steps and for every additional pair of regulating steps a further booster transformer is required with necessary connecting device etc. Also when connecting the booster transformer in opposition power circulates between the main transformer and the booster transformer and causes unnecessary losses. Another system of voltage regulation which has come into use in America combines extra tappings on the transformer and a coupler similar to that in use with our system but includes also a booster transformer and an induction regulator. We cannot enter here into a more detailed explanation of this system but must point out that in accordance with our experience, obtained from installations furnished by us, a continuous regulation of the voltage is not at all necessary because the resistance of a furnace is by no means constant. In most practical cases only 2 or 3 voltage steps are used, even if the transformer is furnished with a very considerable range of regulation. The provision of a booster transformer and induction regulator must accordingly be considered as an unnecessary complication which lowers the safety of the plant in use, particularly as an induction regulator can never be built as safely as an ordinary transformer.

Division of Load.

Besides great dependability, and good efficiency an electric furnace plant must possess a number of other characteristics regarding which a few words will be said next. In the first place comes the question of the division of the load on the network and at the electrodes if 2 or more electrodes are used. In most cases the electrical power for smelting is taken from a three phase system which must be loaded as far as possible symmetrically in order that the furnace shall not upset other plant connected to the network. One single phase furnace only could not be constructed so as to give an even load on a 3-phase system. However booster transformers are connected there always remains a single phase load on the 3-phase supply. If the number of single phase furnaces is even, or if 2-phase furnaces are used the transformers belonging to them can be Scott-connected, so that when the loads on both furnaces are equal a fully sym-

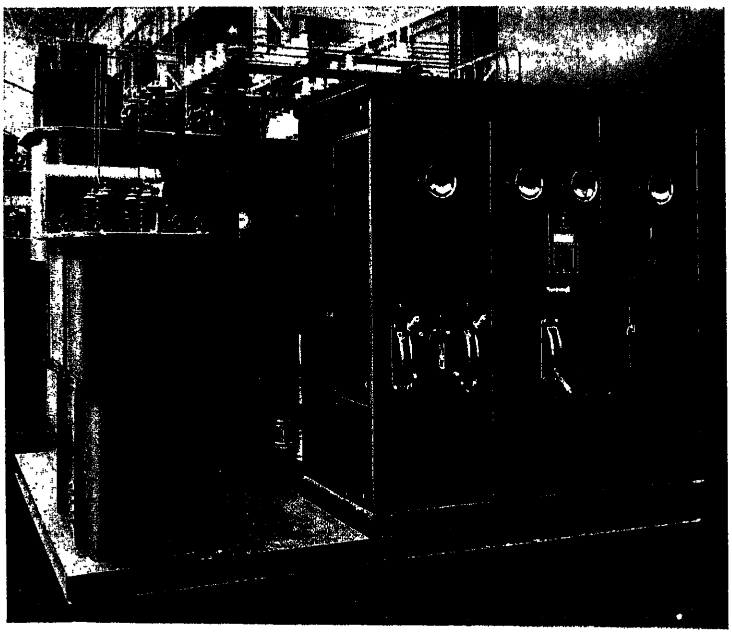


Fig. 13. Portable electric equipment for 1,000 kVA, single phase 12,500/50—180 volts, 25 cycles.

metrical load is obtained on the three phase system. If the furnaces number more than two their transformers can be single phase transformers and when suitable each transformer can be connected between two phases. In that case however it often happens that one of the furnaces must be taken out of use while the others remain at work. This results in the balance of the 3-phase load being upset unless the remaining transformers can be Scott-connected. This however is quite easily arranged and we have developed a system in which by only throwing over a 3-pole two-way switch any transformer can be connected and the remaining ones coupled in Scott-connection. The arrangement is in accordance with the diagram in fig. 9 which also shows how the change over switch should be operated by different combinations of the transformers. If the single phase furnaces number more than 3 they can always be divided up into 3-phase and 2-phase groups and it is accordingly quite easy to maintain a good loading of the 3 phase supply. If the furnace is 3-phase or multi-phase (3, 4, 6, 8, or 9 electrodes) 3-phase or Scott-connected transformers can always be used for maintaining a good division of load on the 3-phase network.

Another division of the power which is probably of even greater importance is the dividing of the energy supplied to the electrodes when these number two or more, so that all the electrodes are used up to the same extent. This not only depends on the manner in which the electrodes are arranged, but also still more upon the reactance in the different phases, and a good division of the power is obtained from the simple principle that all reactance should be as far as possible equally divided between the different phases. As the impedance of the arc is practically free from induction most of the reactance in the installation is to be found in the transformer leads and in the extra reactance coils connected in circuit. The transformers must have the same reactance per phase if they are of single-phase or three-phase type. If they are Scott-connected the main transformer should if possible possess a reactance double that of the secondary transformer (each half of the main transformer should have the same reactance as the secondary transformer). The leads to the furnace should be carried out with each phase run separately, and with the out and return conductors laminated right up to the furnace and as near to the electrodes as possible. This means that in a three phase system the secondary must always be connected in delta or open three phase. Accordingly in fig. 10, which shows a set of leads to a three phase furnace, group 1 combines out and return leads for phase 1. Group 2 the same for phase 2 and group 3 the same for phase 3. In each group the distance "a" between leads belonging to the same coil is small in relation to the distance "b" between the leads belonging to two neighbouring coils. Lastly the distance "c" between respective groups should be as large as possible in relation to the other distances. By making the conductors as far as possible of the same length and by adopting the arrangement above the reactance for the respective pairs of leads is made as nearly as possible the same and the mutual induction between the respective pairs of conductors and between the respective phases is also as small as possible, so that the smallest possible losses take place, due to transformer effect between the different groups of conductors from the windings. In ordinary cases the chief reason for the electrodes not receiving equal amounts of power is to be found in this law efficiency transformer action from one group of coils to the other.

Extra Reactance.

In cases where sufficient reactance for stable working of the furnace does not exist in the transformers, and in the furnace conductors, extra reactance coils must be introduced and care must be taken that these supply a symmetrical increase in the reactance to all phases, (three phase even with Scott-connected transformers) and that they give the required reactance with the smallest possible losses and for the least cost. The first requirement depends on the necessity of maintaining a symmetrical load on the three phase net and heavy unsymmetrical reactance connected in circuit interferes with this. Both requirements are met if one or two 3-phase reactance coils, (or three or alternatively 6 single phase coils) are connected in pairs with the primary windings of the transformer, *i. e.* between the net and the furnace transformers. It is self evident that the first requirement is fulfilled for the above and the second requirement is also met, because the primary current of the transformer is always very small in comparison with the secondary current, and a reactance coil of large current carrying capacity is more expensive and has higher losses than a reactance coil of similar capacity for lower currents (assuming that the working voltage in this last coil is not specially high). Another advantage which is obtained by this arrangement is also that the furnace transformer does not have to deal with the active power and can accordingly be smaller and have a higher efficiency.

If the reactance of the extra coil is required to be variable this can be attained by combining

two reactance coils of different capacity which are connected in series and of which either one or the other, or both, can be short circuited, or alternatively by providing a reactance coil with tappings for one or more different reactances, the change from one tapping to the other being made without breaking the current, simply by connecting on to one tapping before breaking the connection with the other. It should be noted that with this method of altering the connections the change must be made rapidly as an extra leakage field is caused which passes through the tank.

Cooling.

As regard cooling of furnace transformers the same principles as for ordinary power transformers can in general be used although forced cooling can more often be made use of for furnace transformers. This is because during working there are always men available who can attent to the colling arrangements.

Standard Accessories.

Our furnace transformers are usually provided with transport wheels with barring gear, contact thermometers which give the maximum temperature of the oil, and indicating arrangements for the cooling water which operate if there is a stoppage of the water flow in any of the cooling tubes. They are not normally provided with expansion vessels on account of the difficulty of making oil tight joints round the secondary terminals. In one or two cases furnace transformers have been provided with expansion vessels and the arrangement adopted has been found entirely satisfactory, so that where expansion vessels are considered necessary on account of high working voltage they can be fitted.

Portable Equipments.

In order that a furnace may work as safely as possible without interruption it is necessary for the electrical equipment in case a fault develops to be quickly repaired, or replaced by a spare equipment, or changed over with the equipment, from another furnace which is not in use. In plants where a large amount of voltage regulation is provided this changing gives rise to great difficulty as the connections between the furnace, the transformer and the regulating arrangements and switchgear etc. are relatively complicated and require considerable time for dismantling. In order to simplify the changing and removal of faulty parts the whole of the electrical equipment is sometimes made portable. We have developed a number of designs for such installations and several of these have been built. The furnace equipment consists in these cases of a fixed unit, the furnace with the furnace leads, operating devices etc.; a removable unit including the transformer, the winding reconnecter, reactance coils, circuit breaker, disconnecting links etc.; and a connecting unit carrying the connecting leads between the furnace and the transformer, between the incoming primary supply and the circuit breaker, and between the operating device and the winding connecters, circuit breakers etc. worked by them. The movable unit is erected upon a truck and can accordingly be shifted without making any alterations to the connections between the respective apparatus. Figs. 11, 12 and 13 show different arrangement of this movable unit. The connecting unit is so designed that all the connections can be quickly broken and so that the fixed and moving units correspond exactly with each other.

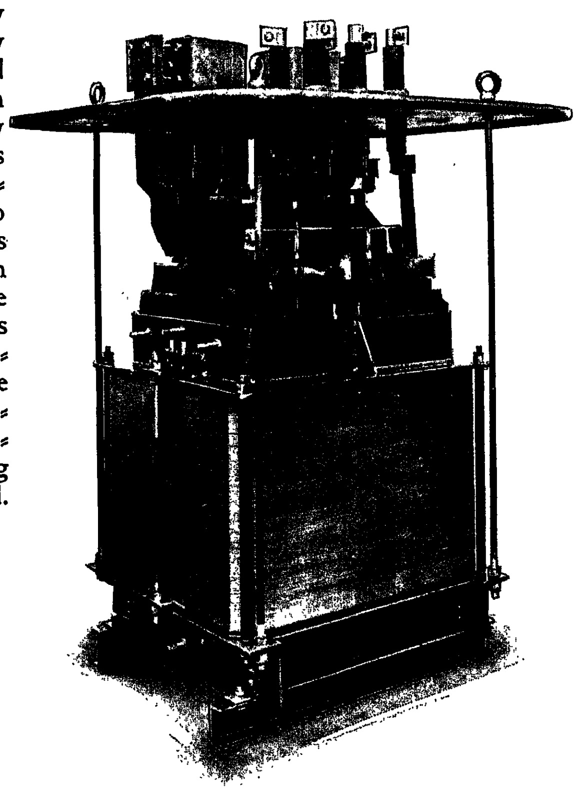


Fig. 14. 900 kVA furnace transformer for 500/55—50 volts, 50 cycles, Scott connected. Overlapping joints

TRANSFORMER OIL.

The importance of transformer oil as an insulating medium in high voltage apparatus is universally recognized on account of its high dielectric strength, low dielectric loss, high insulation resistance, and good cooling qualities.

The transformer oils have, however, the serious disadvantage of deteriorating rapidly at high temperatures, and in this respect are inferior to most other good insulating materials. The deterioration is mainly an oxidizing process, which is still further accelerated by the metals present in a transformer.

Under the influence of all these causes even the best refined transformer oil is sooner or later destroyed at the temperatures allowed in transformers. The oxidizing process forms acid products soluble in oil and acid as well as neutral resinous compounds and asphalts, of which the former are partly soluble in hot oil, whereas the latter are insoluble.

These insoluble substances form the well known sludge deposits on windings and cooling tubes — on the latter chiefly the resinous compounds soluble in hot oil — which impede the cooling of the windings and also impair the heat conduction from the oil to the cooling medium. To this is added an increase in viscosity, which makes the cooling still poorer.

Under the heading above the results of some researches performed in the Asea laboratories will be published in this journal, covering the properties of transformer oils in these respects. This article deals with studies on the effect of the electric field and on the influence of temperature on the stability of transformer oils.

As a result of these researches a new testing method is proposed, in which the combined effect of oxygen, copper, iron, and the electric field is taken into account.

I. *The influence at high temperatures of an electric field in the presence of copper and iron, and with free access of air to the hot surface of the oil.*

Knowing the effect, mentioned in the introduction, of metals and of various conditions existing in transformers, it seemed natural to expect a similar effect from the rather strong electric field to which the oil in a transformer is exposed.

Certain observations made in transformers shortly after the sludge formation has started are in favour of this assumption. In some cases it has been found that the sludge formation is more marked on the terminal leads, and those parts of the winding where the strongest electric field is present, than on other parts of the transformer.

The average stress in the oil close to these most highly stressed parts is generally in the neighbourhood of 10 kV per cm.

The following experiment was made to study this question:

Arrangement of test.

The oil was kept in cylindrical porcelain pots, on the outside covered with a tin foil coating connected to ground. In the pots were placed spirals of edgewise wound iron strips (0.15 % C rolled steel) braced with copper wire, which at the same time served as a high tension lead.

The area of the iron strips was 114 cm^2, and of the copper bracings 12 cm^2. The complete arrangement is shown in fig. 1.

The oil in the pots was thus exposed to the effect of the electric field between the tin foil coating and the spiral, where a voltage of 25 kV was continuously applied. This gives an average stress in the oil of the same magnitude

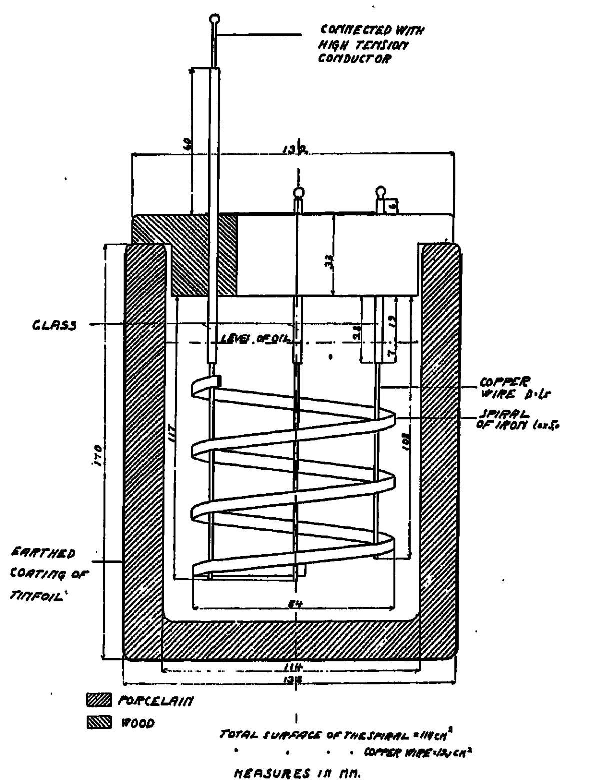


Fig. 1.

as that normally existing at the most highly stressed parts in a transformer, as mentioned above.

Even in the dark room, no corona could be discovered on the sharp edges of the spirals or around the parts of the bracings above the oil. As a further safeguard against undue effects from the possible formation of ozone, the bracings were surrounded by glass tubes reaching from beneath the surface of the oil up through the cover.

The covers protected the oil from dust, but did not prevent air circulation.

In the experiment 6 such cylinders were used each with a capacity of 1 litre. Four of these were exposed to the voltage stated above during the whole time of the test while the remaining two were not subjected to any electrical pressure, although otherwise arranged and fitted up in exactly the same manner.

The pots were all immersed in an oil bath maintained at a temperature of 90°.

The duration of the test was 6 months.

The oil used was an American oil of a well known brand, with an unusually high tar value for its kind, namely 0.21—0.22 according to the Kissling test but entirely without formation of sludge; its serial number is G. 374.

Result.

On opening the cylinders at the end of the experiment the oil was found to have undergone considerable deterioration as follows:

Oil under the influence of electric field with presence of copper and iron:

Exceedingly heavy sludge formation in the oil, a 1 mm thick layer being deposited over the whole spiral; at points where the copper joined the iron this layer increased to 3 mm in thickness. On the porcelain walls a 1 mm thick layer of rather hard deposit was also found, and similarly over the centre of the bottom of the pots with a diameter of about 30 mm (the diameter of the spiral = 82 mm); round the above was a less compact but thicker layer.

The oil was of dark brown colour throughout and was found to have a tar value of 2.45 %.

Sludge quantity, obtained after precipitation with normal benzine = 2.54 %.

Acidity of sludge = 98.8, of oil 4.9.

Oil which was only subjected to heating in the presence of copper and iron.

Heavy deposition of sludge in the oil. No deposit on the spirals except in the vicinity of the copper conductors; none on the sides of the porcelain pots. On the bottom was a loose layer 2—4 mm thick.

The oil was of dark brown colour throughout; tar value = 1.84 %.

Sludge quantity, obtained after precipitation with normal benzine = 1.1 %.

Acidity of sludge = 36.4, of oil 0.98.

This experiment thus shows the great sludge formation in a fairly good oil when heated to quite a normal working transformer temperature under the influence of an electric field in the presence of considerable masses of copper and iron and with air allowed access to the surface.

The increase in the amount of sludge through the influence of the electric field is over 100 % while the acid and soluble tar and resinous compounds are increased by 33 % above the quantity formed in the presence only of copper and iron. In addition to this the sludge formed is of an entirely different character, being found deposited on the parts under electrical pressure, in hard, tightly adhering layers, especially at the outer corners of the spiral where the potential gradient is greatest.

The acidity is 2.7 times higher in the sludge and 5 times higher in the oil.

II. *Effect of temperature on the stability of transformer oils.*

With regard to the much debated question as to what temperature is allowable for the oil in a transformer, it is of the greatest value to know the connection between the time of heating until sludging occurs, and the temperature, and above all to investigate if there is a temperature below which no sludge formation will take place, no matter how long the heating proceeds.

Method of conducting the experiment:

To obtain conditions corresponding as far as possible to those existing when an oil is used in transformers and apparatus, the heating was carried out in open rectangular containers of sheet iron, in which copper was placed. An electric field was not used on account of the complication of the arrangement. Nor were varnish and insulations used as these have been shown to be practically without influence on the sludge formation. (These experiments will be reported on later).

With a view to reducing the time of heating the containers were flat, and with the following dimensions, oil quantity, and surface area of copper:

Surface area of container	100 cm²
Quantity of oil	100 cm³
Area of copper (wire)...............	10 cm²

Four such containers were prepared and placed in an electrically heated sand bath. In order to

maintain the same temperature in all the containers these were placed close to each other in a common tank of heavy sheet iron, which in its turn was sunk into the sand bath. By this means four different transformer oils, as specified below, were heated at the same time under identical conditions.

Heating was carried out with free access of air at 70, 90, 105, 120 and 150°C and the time of heating was determined, for different oils, until the first traces of deposit or turbidness were observed. This time, in what follows, is called the »critical time» of the oil.

The oil was tested every day for formation of deposit, a small quantity being removed in a test-tube after careful stirring; this oil was of course returned to the container afterwards. The examination was made by transmitted light after the oil had cooled, so that sludge soluble in warm oil was also taken into account. In doubtful cases the solubility of the oil was tested in petroleum spirit.

All the oils were filtered before use, so as to remove any turbidness existing beforehand. In addition, when turbidness was established, the tar value and oxygen content of the oil was determined.

The oils used were:

I. Extra high grade transformer oil (G. 512)
II. Best high grade transformer oil (G. 488)
III. Transformer oil I, used for some time in a transformer (G. 508)
IV. Second grade transformer oil used in a transformer for a considerable time (G. 505)

Result:

Oil	I	II	III	IV
Before heating.				
Tar value %	0.009	0.014	0.02	1.40
Tar value after oxygen treatment, %	0.10	0.20	0.80	—
Precipitate	None	Trace	Perceptible	—
Acidity as % SO_3	0	0	0	0.08
Flash point	184	162	168	146
Burning point	215	195	205	185
Viscosity of 20° in °E	5.2	2.84	3.0	8.2
Specific gravity	0.87	0.84	0.85	0.90
Freezing point	—5	—8	—8	—12
Heated to 70° C.				
Critical time, k, hours	3300	2641	2585	785
dk/dt	64.5	125	239	153
Tar value %	1.86	1.87	1.15	1.96
Acidity as % SO_3	0.06	0.07	0.06	0.09
Heated to 90° C.				
Critical time, k, hours	2064	911	597	120
dk/dt	64.5	55.7	37.0	8.0
Tar value, %	0.44	0.44	0.42	1.84
Acidity as % SO_3	0.04	0.025	0.03	0.15
Heated to 105° C.				
Critical time, k, hours	1073	353	233	65.5
dk/dt	64.5	25.8	16.0	3.25
Tar value, %	0.54	0.38	0.38	1.80
Acidity as % SO_3	0.035	0.030	0.035	0.12
Heated to 120° C.				
Critical time, k, hours	137	65	50	17
dk/dt	52.0	9.0	5.4	1.35
Tar value, %	0.58	0.75	0.77	2.06
Acidity as % SO_3	0.04	0.05	0.055	0.10
Heated to 150° C.				
Critical time, k, hours	6	4.5	4	2.5
dk/dt	0.48	0.45	0.25	0.085
Tar value, %	0.66	1.03	0.80	2.19
Acidity, as % SO_3	0.06	0.07	0.06	0.11

It will be noticed that the derivative dk/dt is also given for the curves over the critical time, k, as a function of the temperature of heating t; these curves are given in curve group I (fig. 2.). The curve group II (fig. 3.) represents the derivatives, which show more clearly the tendency of the oil towards stabilisation.

These curves show that oils III and IV *i. e.* those which the Kissling tar formation test, and also the test in question at above 70°, showed to be the poorest ones, show the most decided tendency to stabilisation as regards sludge formation, and for these 60° would seem to be admissible as a stable temperature. For oils I and II, which came out decidedly better in the above tests, this is not the case when the low temperature of 70° is in question.

On the supposition that the established form of curve is maintained, even at lower temperatures, oil II should be stable at about 30°, while oil I would never reach a stable temperature as regards sludge formation.

It is worth noting that the oils which had been in use for some time showed special tendency to quick stability. This may possibly be explained by the fact that all oils — even the best — contain a small amount of already partly formed, resinous products soluble in oil, which are not destroyed by refining, or which are formed during the time the oil is in stock. These substances can be expected to form insoluble asphalt substances (asphalts) quickly with free access of air, even at low temperatures, by oxidation, intermolecular action, and condensation. If now an oil has been some time in use and has also undergone heating this alteration has already taken place, and the least permanent portion has been precipitated, so that such an oil would be expected to be stable at the lower temperature. Certainly during this a

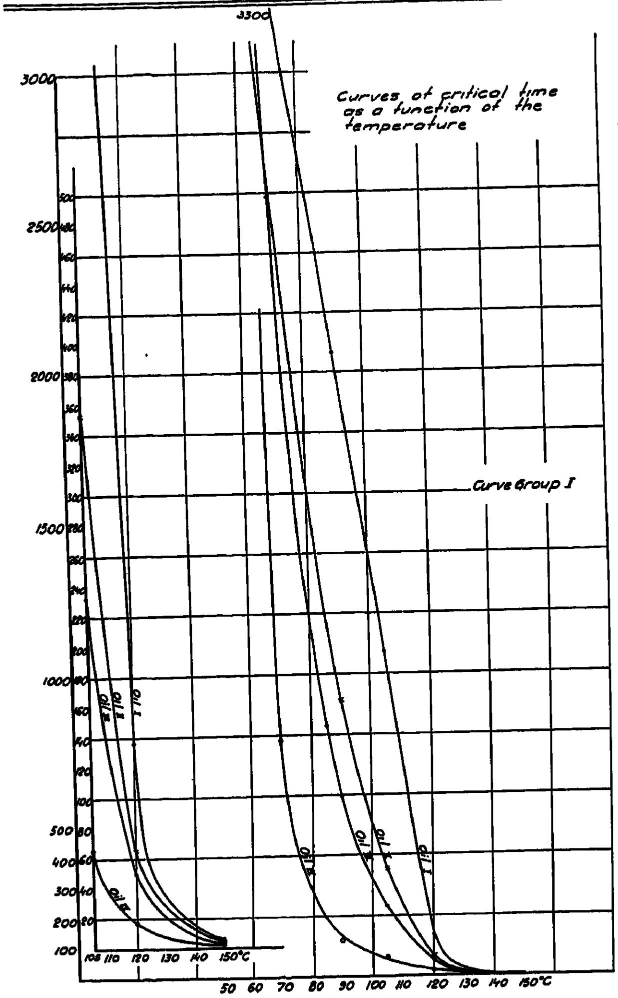


Fig. 2.

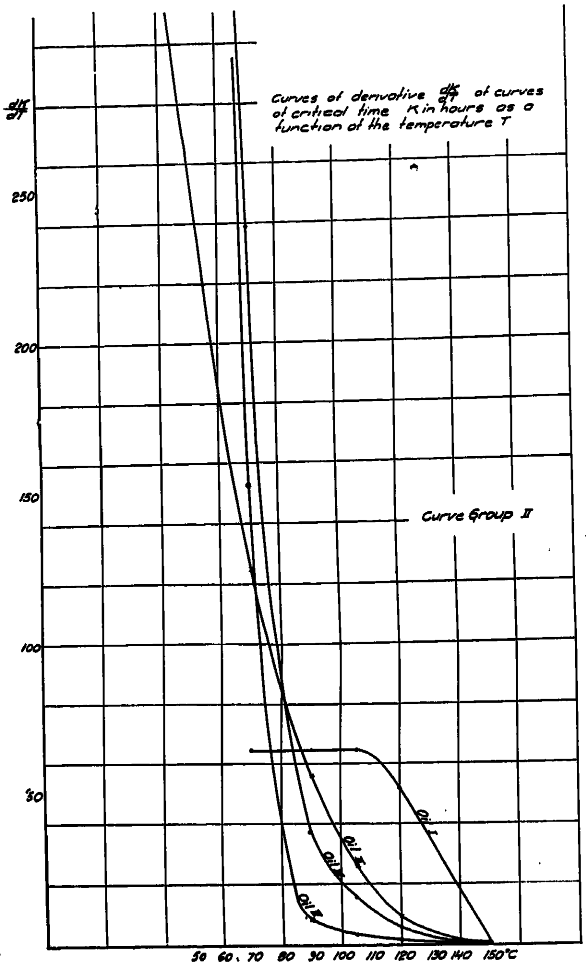


Fig. 3.

further depreciation of the oil has taken place and new resinous and acid compounds have been formed, but it is not unlikely, that these are of another character and require a higher temperature or a very long time at a low temperature for transformation into insoluble substances. The fact that oils III and II are of the same kind speaks in favour of this conclusion. A further likelihood of the above hypothesis is indicated by the extraordinary increase in the critical time for 70°, above that at 90°, for oil IV, which has the highest tar value *i. e.* the greatest amount of completely formed soluble acid products of decomposition. This is also the case with oil III, which comes next in order, both as to the question of the proportion between critical time for 70° and 90° and in tar value.

It may be mentioned further, that it was shown, that certain oils which were fairly good according to the Kissling test, developed resinous products when kept standing in stock transformers.

The hypothesis put forward above leads finally to the conclusion that formation of resinous products, which takes place in a good unused oil at low temperatures is without great significance to the good operation of transformers or other apparatus.

As the above depends entirely upon the supposition that the connection found between critical times and temperature is correctly given by the curves drawn, and still holds good even for low temperatures, a continuation of the experiment is being made for control purposes by warming oil to temperatures below 70°C.

The part of the experiment already completed clearly indicates, however, that the stable temperature is below 70°C — in the most fortunate cases at 60°C — and that the danger of sludge formation increases greatly with temperatures above 70°. This shows the importance of keeping the oil temperature as low as possible, preferably between 60° and 70°C.

On examining next the tar value and acidity

found with different heating temperatures it is discovered that for the same oils these are highest after heating up to 70°, 120° and 150° respectively, which also indicates that the oils undergo oxidation chiefly at very low and very high temperatures. In the region of 90°—105°C the acidity and tar values are relatively low suggesting that the sludge formation at these temperatures is chiefly to be ascribed to polymerisation and condensation, while absorption of oxygen is of quite subordinate importance.

As the permanency of two oils against polymerisation, condensation and oxidation can, of course, vary according to the constitution and degree of saturation of the hydrocarbons contained therein, it is evident that the dependence of the sludge formation of temperature can exhibit wide dissimilarity and their heat-permanency curves may intersect.

Finally it should be pointed out, that the critical time of an oil can not be regarded as the only deciding factor in regard to its value as a transformer oil. Other investigations — to be published later — have shown that different oils behave very differently after sludge formation has started. The amount of sludge formed during a certain time is very different for oils of different origin and refinement, in spite of similar values of the critical time.

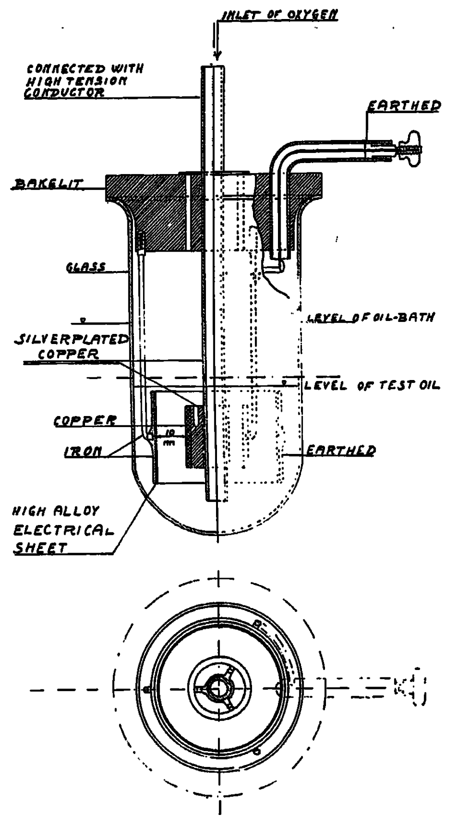


Fig. 4.

III. *A new method of testing the quality of an oil in regard to durability against heating in transformers and apparatus.*

The lack of agreement between various methods of testing the quality of an oil is probably generally recognized. This is quite evident on account of the great differences in regard to temperature, presence of substances affecting the sludge formation, the treatment in general, and methods for determining the quantity of products formed.

This new method is based upon the requirement that no consideration should be given to arbitrarily chosen reactive substances or products, and on the contention that it is incorrect to judge the oil after an arbitrarily chosen time of action.

Since the methods of refining generally are arranged to make the oil as stable as possible against the treatment given and the substances present in the test, it has been required from this new test, that all substances and conditions usually present in transformers, which can be shown to have an appreciable effect on the oil, should also be included in the test. Otherwise special types of oil are likely to appear, which may pass the test but nevertheless fail to give satisfactory results in practice. For instance, the test includes common stoft steel as well as silicon steel, since iron has been shown to accelerate considerably the sludge formation, although not to the same extent as copper. Iron soap has also been shown to be present in the sludge formed under the influence of an electric field (according to I). A great influence of such soaps is found.

The test is performed under the influence of an electric field with an average density of 10 kV per cm.

The heating temperature has been fixed at 100°C, which is only slightly above the maximum temperature for transformer oil allowed in the standardization rules of certain countries. To go higher than 100° was not considered safe.

Finally it should be mentioned that a certain quantity of oxygen (1 litre per hour and 60 gr. of oil) is blown through the oil. The oxygen is dried and purified in passing through concentrated sulphuric acid and slaked lime in succession.

The heating takes place in an oil bath, reaching a certain distance above the level of the oil in the test; the temperature is controlled within ± 0.5°C with a thermostat, and a uniform temperature is maintained by means of a stirrer. Three tests are made with different heating times so adjusted that a good oil shows very

little sludge (about 0.02 %) after the shortest time (70 hrs.), but a large quantity (about 0.2 %) after the longest time (200 hrs.). With the aid of these values is plotted a curve of the sludge quantity in function of the time, showing the time required to start sludge formation (by extrapolation) as well as the increase in sludge with time.

In testing oils with known characteristics, however, only one test will be necessary, preferably with 100 hrs. heating time.

The arrangement is shown in fig. 4, which is drawn in scale 4:10.

The oxygen is admitted through the central tube, which also serves as the high voltage terminal. The tube as well as the cross carrying the smaller copper cylinder are made of silver-coated copper in order to prevent these parts having an appreciable influence upon the test. At normal voltage there is no corona on any part of the apparatus, so that all ionization or ozonization of the oxygen is excluded. Nor has corona been noticed in the oxygen bubbles passing through the oil in spite of the electric field between the two cylinders.

The inner cylinder is made of copper, the outer one of iron. The latter consists of two parts welded together, of which the inner one is of silicon steel, the outer one of soft steel (0.15 % C). The iron cylinder is grounded through the bracings.

Both cylinders can easily be removed for cleaning. Before starting a test, the copper cylinder is heated red hot and the oxide formed is reduced by alcohol; the rest of the apparatus is pickled, washed, and dried. After cleaning, to avoid oxidation, the active parts (the cylinders) should be kept in bensol until they are placed in the oil.

The sludge quantity is determined as in the Michie test: the benzine used should not contain more than 2 % aromatic hydrocarbons, and should distil over below 95°C.

It has been found necessary to wash the sludge formed once with this benzine after drying, because a slight quantity of oil is likely to adhere mechanically to the sludge. In drying, the sludge usually forms a compact mass, whereby the oil is collected on top of the sludge and can be washed away without removing any sludge. Tho check this, however, the benzine used is afterwards filtered.

The sludge quantity is given as a percentage of the oil quantity.

The acidity is determined for the sludge and for the oil after removal of the sludge.

Repeated tests have been found to agree very well.

In order to avoid exaggerated influence from either one of the factors affecting the test, which might give a difference between test results and practice, it will be necessary to properly adjust the active metal surfaces and the quantity of oxygen against each other and the quantity of oil. It is intended to perform this with comparative tests in actual transformers with a number of oils differing in refinement as well as in origin.

The results of these tests will be published later, as well as studies on the influence of the strength of the electric field, of different sizes and arrangements of the cylinders, different quantities and temperatures of the oxygen, the effect of the difference in level between the oil to be tested and the oil bath, and of the heating temperature, and also tests over the increase with temperature, for different oils, of the sludge and the acidity.

A CONTINUOUS CURRENT PLANT FOR SOUTH AFRICA.

Fig. 1. Five panel switchboard of black enamelled slate. Front view.

At the beginning of May this year Asea supplied a continuous current installation to Messrs. Findlay, Durham & Brodie (agents in London for Messrs. Reunert & Lenz) for Kokstad in South Africa and as special plant had to be put in hand, which is of a very interesting nature, we give below some general particulars regarding it.

The plant delivered consists of two generators, and complete switchgear for distribution and running the generators in parallel, also a three-wire accumulator battery. The generators, which, in accordance with the customer's requirements, normally run compounded, are arranged for running in parallel and also designed for charging the battery.

Battery.

This consists of 240 cells and has a total capacity of 290 ampere-hours. The maximum charging current is 72 amperes.

Generators.

These are of type K-13 and designed for direct coupling to 60 h.p. engines. The maximum output is 40 kW at a voltage of 2×220 volts at 600 r.p.m., corresponding to a load current of 91 amperes. They are built with sliprings and three-wire compensators for a maximum of 15 % of the load current in the neutral. The series windings are arranged in two circuits as shown in the connection diagram, fig. 3.

Booster Set.

This consists of a K-9 generator for 72 amperes and 13 kW maximum output at 220 volts. The machine is shunt wound and arranged for

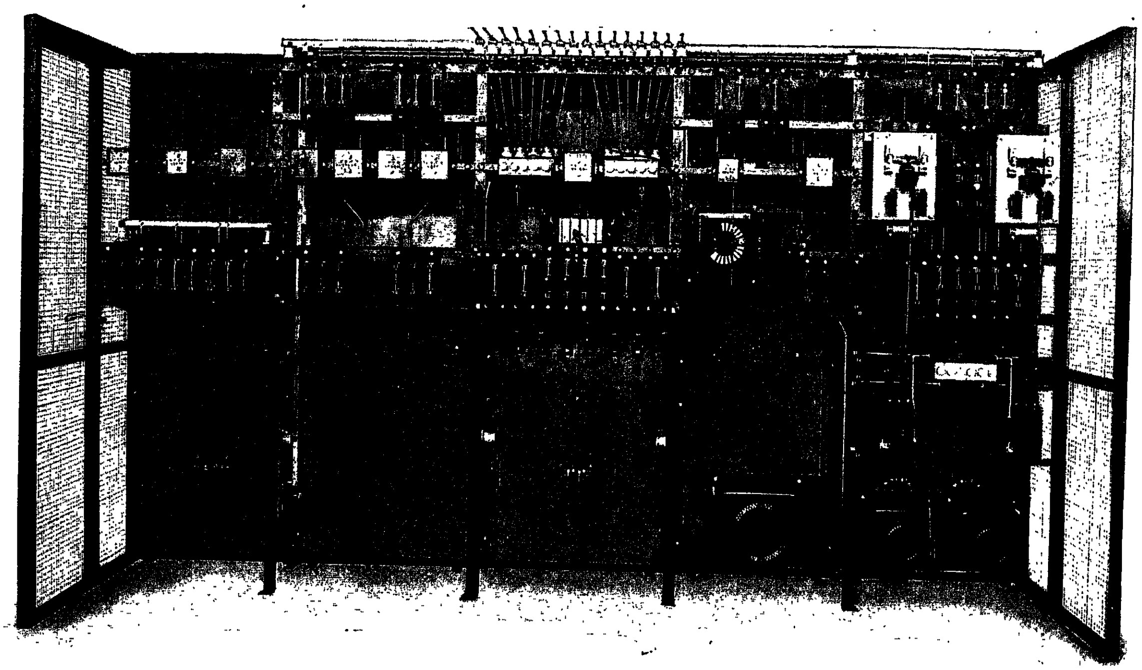


Fig. 2. Five panel switchboard. Rear view.

separate excitation at 440 volts. The voltage of this generator is arranged for regulation by resistance from 0—220 volts. The generator is direct coupled to a type K—9 shunt wound continuous current motor for 440 volts and 1,000 r.p.m.

Switchboard.

Scheme of Connections.

As the machines are normally arranged for running compounded it was necessary, when running them in parallel without the battery, to balance them by means of an equalizer. As, in this special case, the generators are arranged with the compound winding in two circuits, double equalizer bars are arranged between the machines. When running the machines in parallel it was necessary to arrange for the series windings to be cut out and for the equalizer connections to be broken at the same time. This requirement has been met by the double-pole change-over switches 9, and these are arranged for changing over without breaking circuit; the second requirement regarding the disconnection of the equalizing bars is fulfilled by the help of the 2-pole switch, 12 in the diagram. In the main circuit of the generators double-pole overload circuit breakers with reverse current relays are placed, for connecting and disconnecting the machines from the busbars. By the 2-pole knife switch 14 and the single-pole quick-break switch 13 each generator can be isolated from the busbars. In addition each generator is provided with a kWh meter, volt-meter, two ammeters, and shunt rheostat.

The charging arrangement was supplied, in accordance with the wishes of the customer, with simple cell regulator. All connections for charging the whole of the battery, or one or other half of it, are made by the two double-pole change-over knife switches which are arranged to break circuit (A and B in the connection diagram) and by this arrangement all interlocking gear has been dispensed with and complete safety still obtained against incorrect operation.

The whole battery is charged with the switch A in its upper position and during this operation it is immaterial whether switch B is closed in the upper or lower position. Discharge of either half of the battery can only take place with the switch A in its lower position. The position of the switch B then determines which half of the battery is connected.

The battery is connected to and disconnected from the busbars by 4 single-pole quick-break switches (13 in the coupling diagram).

The booster generator is protected by a minimum current release in its armature circuit (15).

In addition the switchboard is furnished with 7 outgoing three-wire circuits each provided with switch, fuses, and instruments, as shown in the diagram of connections.

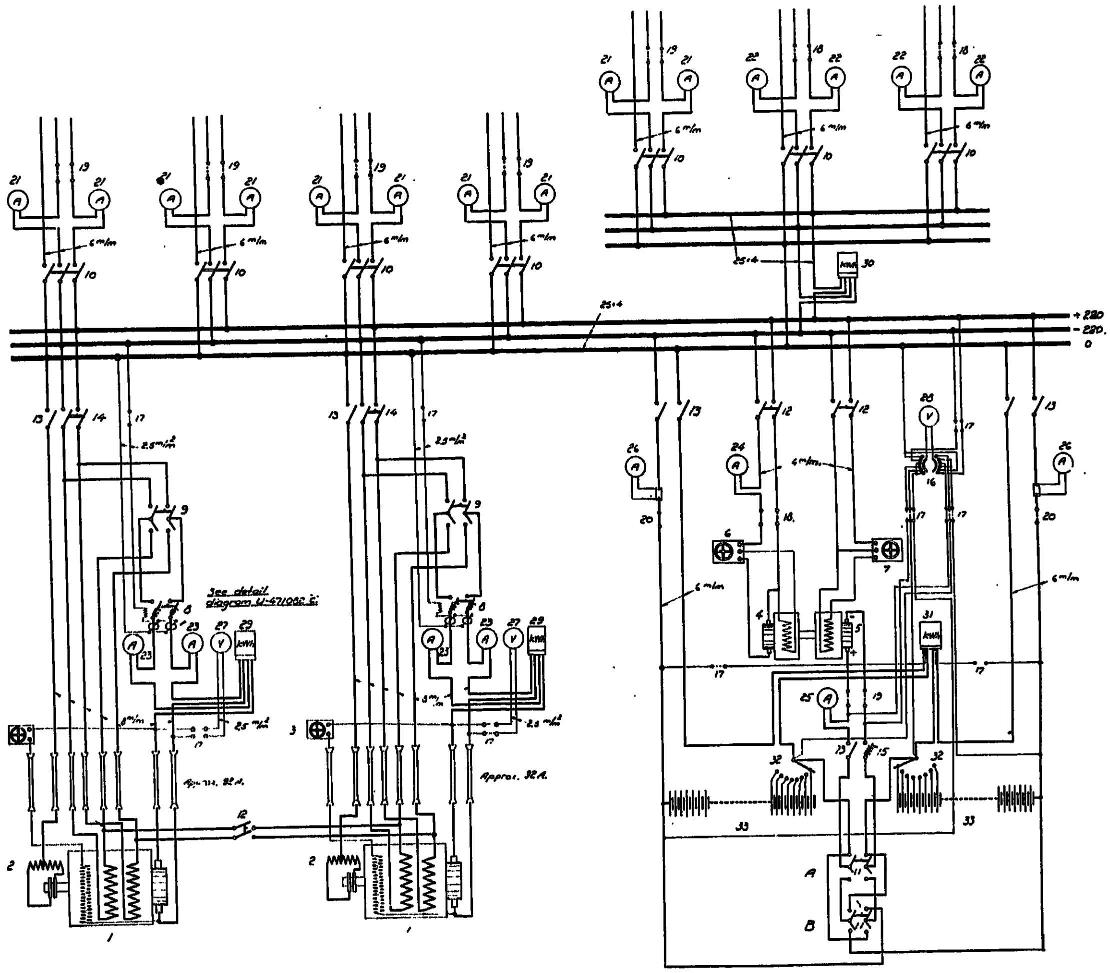


Fig. 3. Diagram of connections.

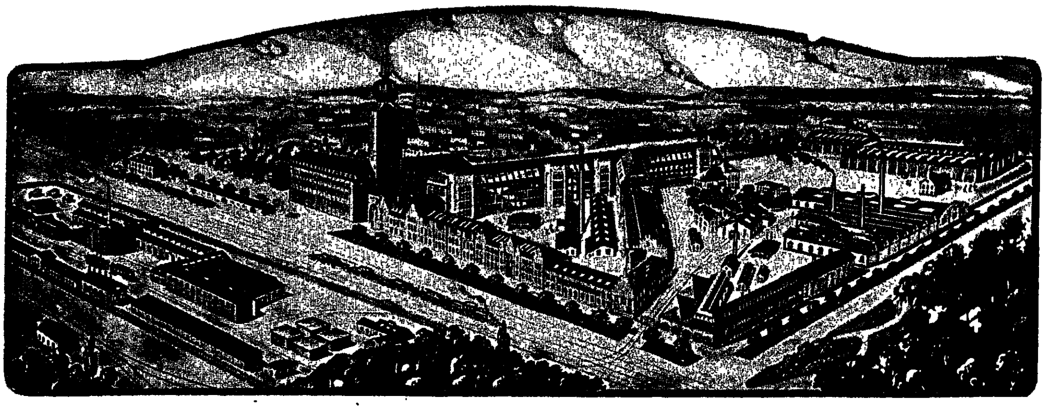
General.

As regards the appearance of the switchboard this can be gathered in a large degree from figs. 1 and 2, which show front and rear views respectively of the switchboard after erection in our shops.

The switchboard is furnished with 5 black enamelled slate panels, each having a total height of 2.4 m, and the total length of the board is 4.3 m, the last being determined by the customer's requirements.

Panel 1 carries all the instruments and apparatus for the two generators; panel 2 all apparatus for the booster set. Panel 3 is the battery panel, and panels 4 and 5 are the outgoing feeder panels.

All switches, with the exception of the generator disconnecting links (14), are operated from the front of the panels and all operating arrangements are furnished with indicating plates.



Asea's head office and works in Vesteras, Sweden.

Vesteras 1924, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

WITH THE COMPLIMENTS
OF
EWING & CO., LTD.,
4, CLIVE ROW, CALCUTTA.

AGENTS FOR
THE SWEDISH GENERAL ELECTRIC LTD.

SWEDISH GENERAL ELECTRIC LTD
5, CHANCERY LANE—LONDON

NOV.-DEC.

...nce should be addressed to the Editor, Publicity Dept.
Asea, Vesteras, Sweden.
Perm... given to reprint articles or extracts from this journal,
on condition that the name — Asea-Journal — is clearly stated.

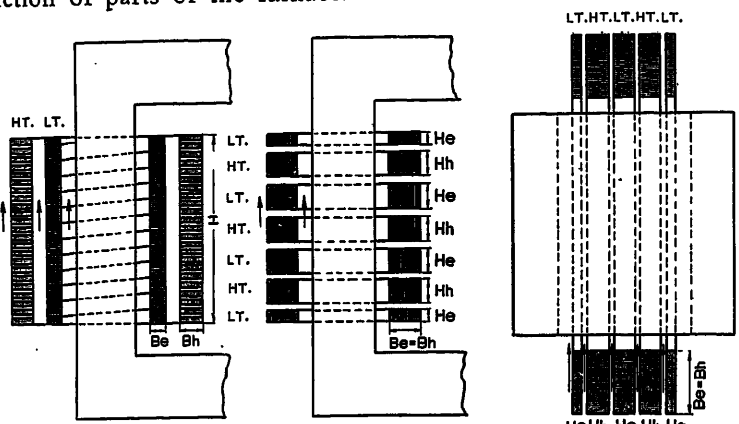
1924

Asea three-phase transformers for outdoor installation, each 2,500 kVA, 6,000/50,000 volts. Belgium.

ELECTRIC FURNACE TRANSFORMERS.

Introduction.

The most important characteristics of the electrical equipment of furnaces are dependability, great resistance to damage by rough usage, and suitability of electrical qualities. A »shut down» caused by the failure of the electrical equipment always means economic loss and sometimes entails the destruction of parts of the furnace. The electrical plant must be designed with special regard to furnace conditions, and also with due consideration to the men working it, who are used to handling heavy things, and are consequently not usually very careful. Lastly, uninterrupted and economical operation of the furnace is required and this demands thorough interchangeability between all parts of the electrical plant. The principles on which Asea's present-day furnace transformers are constructed, and the extent to which they meet the special requirements mentioned above will be shown in the following.



a. Core transformer with concentric windings. b. Core transformer with pancake coils. c. Shell transformer.

Fig. 1. Cross section through core and shell type transformers through the axis of the windings. The arrows give generally the direction taken by the cooling oil.

Comparison between Shell & Core Types.

The chief points of difference between a furnace transformer and an ordinary power transformer are that a transformer for furnace work is dimensioned for a secondary current which is very high in comparison with the output; is usually provided with extra tappings on the primary winding for varying the secondary voltage in the ratio of 1:1.25 or 1:3; and finally is often designed to withstand direct short circuits on the secondary side as well as heavy mechanical stresses of various kinds. For power transformers the core type has in our experience been found most suitable, and at the present time practically all power transformers are made in this way. This type, however, has certain drawbacks when considered in relation to the special requirements of furnace transformers. For sizes above 100 kVA these last are accordingly always constructed of the shell type.

It is not intended to consider here the fundamental differences between core and shell type transformers, we only wish to point out the properties which determine the relative fields of use for the two types in the present case. We accordingly refer to fig. 1. The windings on a core transformer, in order to obtain good cooling, suitable insulation to core and between windings, and small stray losses in the conductors, must be executed with small radial breadth in proportion to their axial length. Such coils are accordingly long and narrow and with few turns per coil; when they are made for heavy currents they must necessarily be divided into a large number of parallel conductors on account of eddy current losses. The windings in a shell transformer must, in order to obtain the same good characteristics, be made with great radial breadth in proportion to their axial length. The coils in a shell transformer for heavy currents can therefore be furnished with massive copper conductors "wound" on edge so as to give great mechanical stability, without fear of the eddy current losses becoming too high. The high tension windings, *i. e.* those which carry a considerably smaller current, are wound on the same principle for both large core and shell transformers, of copper strip wound flat in spiral coils. From a mechanical standpoint accordingly the difference between the windings in core and shell transformers is that in the former they are less stable mechanically, and more difficult to manufacture. The terminal leads in addition must be fixed to the many conductors of the winding by cable clamps and bolts, while in shell transformers these leads can be sweated direct to the coils which are themselves massive copper conductors and thus make a continuous whole with the leads.

The arrangement of extra tappings on core type transformers always entails special consideration in order that they may not give rise to undesirable effects. In particular when tappings are provided so that a considerable part of the windings are disconnected, special arrangements

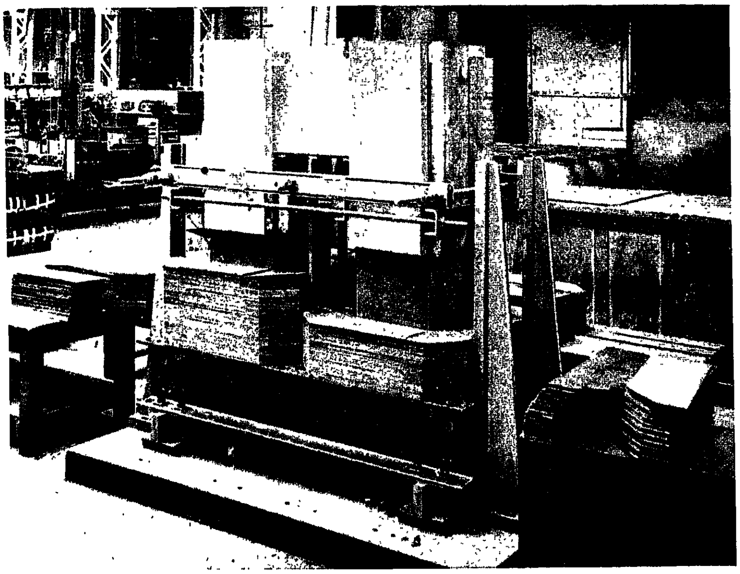


Fig. 2. Assembling core plates on a shell transformer.

must be adopted, so that the high and low tension windings shall not become magnetically unbalanced, and large eddy current losses and considerably increased reactance occur in the transformer when the tappings are changed. Where many regulating steps are required and when more than 30 % of the winding is to be disconnected, these difficulties become very great in windings for over 1,000 volts, and it is accordingly very difficult to use core type transformers at all in such cases for furnace work. In a shell type transformer, however, no difficulties whatever are met with in providing extra tappings by which 60 or 70 % or more of the winding is disconnected. The only point demanding care is that the tappings are so arranged that the reactances of the parallel connected low tension coils are as far as possible the same. The advantages of the shell type transformer over the core type transformer, as regards the bringing out of extra tappings for large percentage differences, are accordingly very great, and constitute the chief reason for the use of shell type transformers for furnace work.

As shell type transformers are always constructed with rectangular coils and core type transformers with circular coils, and as in a shell type transformer the coils of the high and low tension windings are distributed alternately in the axial direction while the windings in the core type can be made concentric, the stresses which normally occur in the axial direction in a shell type transformer are very much greater than the corresponding stresses in a core type transformer, especially if the last is not furnished with extra tappings or has windings which are magnetically well balanced. The stresses occuring in a radial direction are smaller in the shell type transformer, but the core type transformer has the advantage that these radial stresses on account of the circular form of the coils are taken up by the copper in the winding itself, while the rectangular coils of the shell type transformer must be very strongley supported in order that they will not be deformed when short circuits occur. It may be said in parenthesis that the radial stresses in a shell type transformer are not of such great importance, since on account of the construction of the iron core they are neutralised to a certain extent by the attraction of the core. The mechanical stresses which are dangerous to the windings in a shell type transformer are accordingly always considerably larger than in a core type transformer with concentric windings, and in order to obtain a construction entirely satisfactory in use it is necessary to provide winding supports of a specially heavy nature in shell type transformers. There is, however, no particular constructional difficulty in making these winding supports sufficiently safe, and accordingly the drawbacks due to the greater mechanical stresses in a shell type transformer are not so great. They must, however, partly on this account be made heavier and more massive than corresponding core types, and they are accordingly also somewhat more expensive to manufacture.

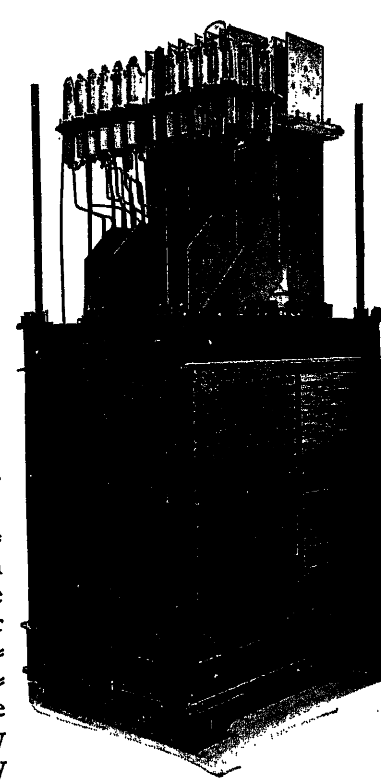


Fig. 3. 4,000 kVA furnace transformer for 10,000/60—100 volts, 50 cycles, Scott connected. Transformer arranged with overlapping core joints.

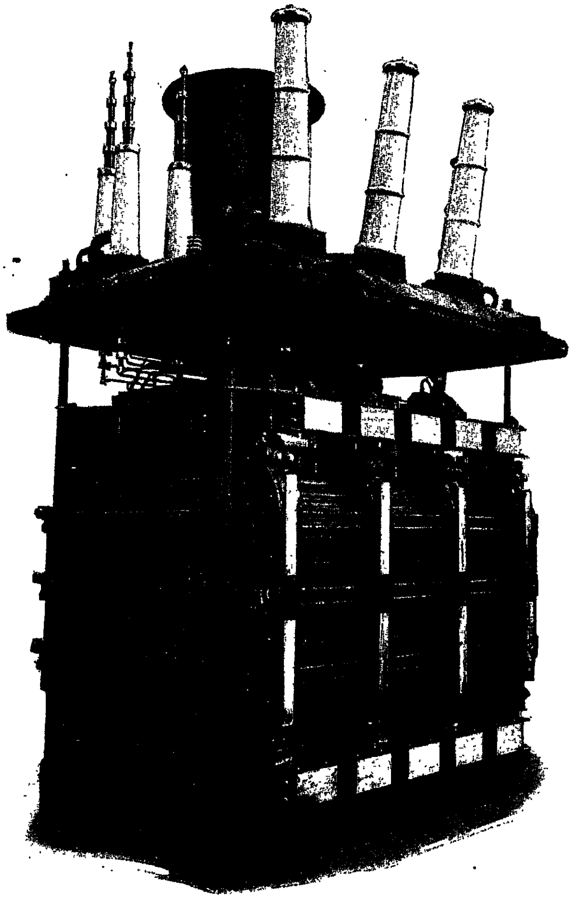


Fig. 4. 3,000 kVA power transformer for 72,500/40,000 volts, 50 cycles. Transformer with butt jointed core.

Constructional Details of Shell Type Transformers.

During the long period in which we have manufactured shell type transformers, we have had the opportunity of testing many different principles of construction which have proved to be more or less dependable in service and suitable for their work. This long experience has been brought to bear on the design of our present type of shell transformer, and in the following some of the principal details of our present construction will be dealt with.

The Core.

The cores are always constructed with overlapping joints (see fig. 2) and without any bolts traversing the core plates themselves. The advantages of this are that the losses in the iron are the smallest possible, that the transformers work silently, and lastly that the stacks of core plates themselves act as a mechanical support for the windings. By heavy end supports which are placed over and under the core plates and drawn together by stay bolts outside the core, (See fig. 3) the core is tightly pressed together and this pressure and the friction between respective core plates in the joints is sufficient to take up the mechanical stresses from the coils. In this way no supports are required for holding the core together in the direction of the plane of the core plates. When the core is made with "butt" joints instead of with interleaved joints, such supports are absolutely necessary for taking up the mechanical stresses from the coils; and the construction is accordingly much more heavy and clumsy. (Compare the illustrations in figs. 3 and 4 of which fig. 3 shows a 4,000 kVA smelting furnace transformer with overlapping joints and fig. 4 a 3,000 kVA transformer with butt joints. In general it is thought that butt joints are an advantage in shell type transformers on account of the greater ease in erecting and dismantling. According to our experience this is not the case. The erection of a transformer with butt joints, reckoning the time for placing the different stacks of core plates in position, takes at least as long as the erection of a transformer with interleaved joints, and the dismantling of a transformer in a case where one or other of the coils is defective is practically as simple. On a transformer with butt joints it is not necessary to dismantle the whole core for repairing some part of the winding, but on transformers with interleaved joints only one side need be loosened out, and the defective coils removed from the remaining part.

Windings.

The windings are built up as before described, the high tension coils being of spiral wound strip and the low tension coils of massive flat copper bars. The construction of the former is in accordance with fig. 5. The coils are wound of copper strip on the flat and this construction affords the advantage that the coils are very compact and strong mechanically. The conductors themselves are cotton covered and for high voltages a combined paper and cotton covering is used. In addition presspahn or paper is introduced between turns to increase the strength of the insulation. As the conductors are wound

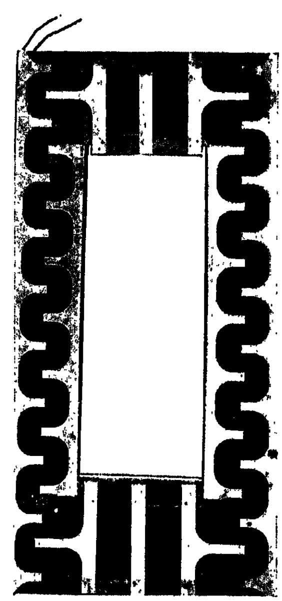


Fig. 5. High tension coil for 1,000 kVA furnace transformer. 12,500/50—180 volts, 25 cycles.

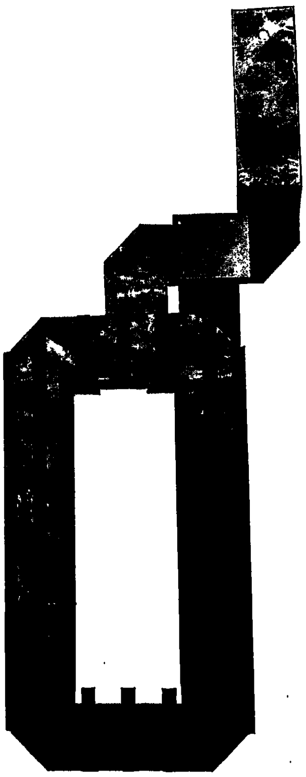


Fig. 6. Low tension coil for 1,000 kVA furnace transformer. 12,500/50—180 volts, 25 cycles,

as above and with presspahn placed between them there is practically no possibility of the insulation between the conductors breaking down in use. Such windings are accordingly particularly free from breakdown troubles. The safety of the coils in use is also increased by impregnating all the coils in a vacuum with oil resisting varnish so that the risk of the insulating material absorbing moisture is greatly decreased whilst the coils are rendered very rigid. No extra strengthening of the insulation on the conductors near the terminals is furnished on furnace transformers, but insulation of the same strong character is used throughout in all parts of the windings, this having shown itself to be the best and safest principle when it is necessary to protect against abnormal pressure rises. The low tension windings are always constructed of flat copper bars welded together and are left bare and not provided with any insulation round the conductor itself, see fig. 6. These coils are insulated from one another and from the core and high tension windings by the insertion of presspahn and wooden strips.

Insulation.

As regards the insulation between the respective windings and between the windings and the core, it is only necessary that this shall be dimensioned in a suitable manner to meet the electrical requirements. The insulation must also have very good mechanical characteristics so that it will not shrink or settle after being some time in use, also that the mechanical pressure exerted on the windings when the transformer is fully assembled will not decrease with time, allowing the coils to become loose. If the coils can move in this way the stresses set up on a short circuit are much more dangerous than if the coils are heavily pressed the whole time.

In order to obtain insulation which corresponds to the requirements as regards mechanical strength we now always employ presspahn, fibre, bakelite etc. materials which besides being strong do not shrink or warp after being in use for some time. The manner in which the insulating is carried out is shown in fig. 5. Round the long sides of the coils are laid pressed U-shaped strips of presspahn, which are so formed that not only is a long leakage path from the winding to iron obtained, but also as large a part as possible of the winding is open, giving a large area for dissipation of heat between the conductors and the oil in the oil channels, so that the windings are effectively cooled, and the copper can be fully utilised without fear of any part of the winding reaching a temperature dangerous to the transformer. Between respective coils are laid, in addition, presspahn guards alternating with the oil channels and depending on the working voltage and guaranteed test pressure.

For taking up the mechanical pressure and ensuring that the coils will be immovable, even under the pressures resulting in the event of short circuits, heavy wood strips are placed between the core and the coils after the transformer core and windings are erected and the end supports assembled. The free coil ends over and under the core are forced together by special press-screws (see fig. 14) acting on heavy plates.

Additional Tappings.

In arranging extra tappings for regulating the secondary voltage it is in general only necessary

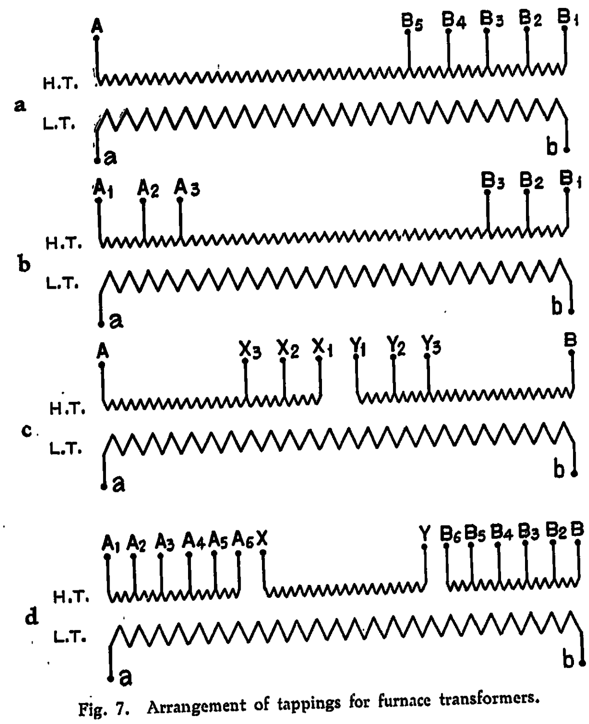


Fig. 7. Arrangement of tappings for furnace transformers.

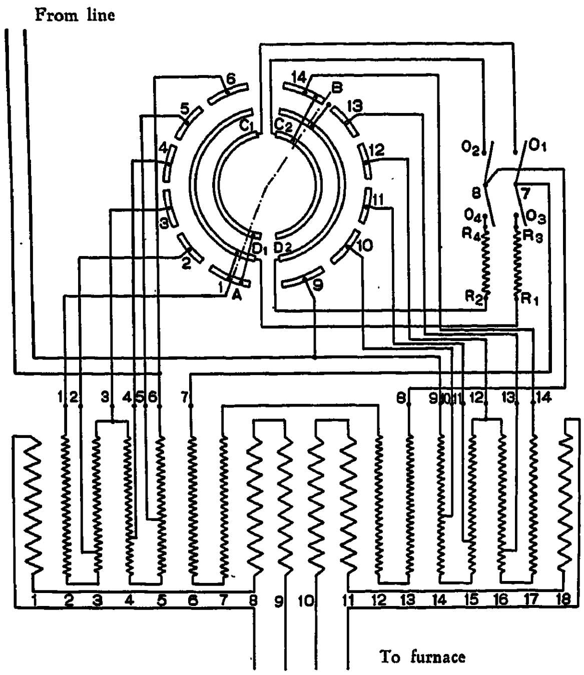


Fig. 8. Connections of a transformer and winding coupler for large pressure variation.

to consider three things. In the first place of course they should be so arranged as to give the required regulation. They should be placed so that they do not endanger safe operation; so that, as far as possible, the same reactance is maintained in secondary coils which may be connected in parallel; and so that no voltage appreciably higher than the normal can exist, during working, across any parts of the transformer windings.

Our additional tappings are always made with copper strip which is riveted and soldered direct to the conductors themselves, carefully insulated in the coils and brought out through the oil channel between the respective coils in flat bakelite tubes. By this arrangement the risk of breakdown by a failure at the tappings is reduced to a minimum. To maintain the same reactance in the secondary coils the tappings must as far as possible be placed symmetrically with regard to the respective windings. This is, however, not absolutely necessary since in a suitably arranged furnace installation the parallel connection of the respective secondary coils is effected at the furnace itself. To the reactance of each coil is therefore added the reactance of the leads between the transformer and the furnace. As the reactance of these leads is in most cases two or three times greater than that of the coils themselves a relatively large difference in the reactance of the transformer coils has a small effect on the division of the current in different coils during normal operation. In this connection it should be pointed out that when carrying out a short-circuit test on a furnace transformer with many parallel connected coils in order to determine the short-circuit voltage and copper losses, the secondary coils should always be connected in series so that the same current passes through all the coils, since with parallel connection there is no means of ascertaining what division of current is actually being obtained. Our guarantees regarding transformer copper losses and reactance are always given on the assumption that a short circuited test for their determination will be carried out in the above manner. If the extra tappings for varying the secondary voltage are placed at the end of the high tension winding, as shown in fig. 7a and b, then when the full voltage is applied across terminals A and B_5 or across A_3 & B_3 a higher voltage will be obtained between terminals A & B_1 or A_1 & B_1 respectively. In cases where the regulation amounts to a maximum of not more than 30 to 40 % (the highest voltage being accordingly 30 to 40 % greater than the working voltage) this is not of great importance since the test pressure is always twice the working voltage + 10,000 volts and furnace transformers are not normally constructed for higher working voltages than 20 kV. If however the alteration is greater, the ratio being say 2 or 3 and above it will be seen that the arrangement in fig. 7a and b will give rise to dangerous pressures, especially if the transformer is not designed for

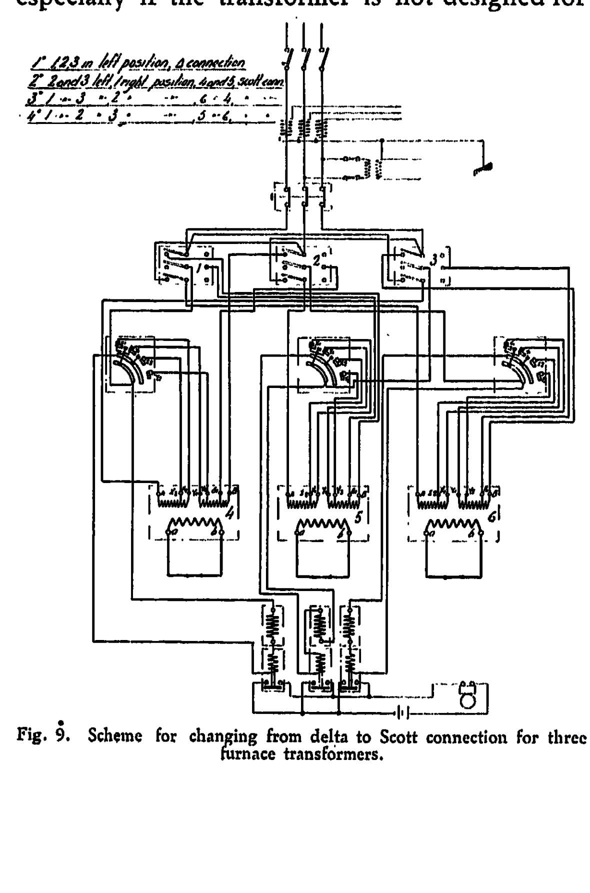


Fig. 9. Scheme for changing from delta to Scott connection for three furnace transformers.

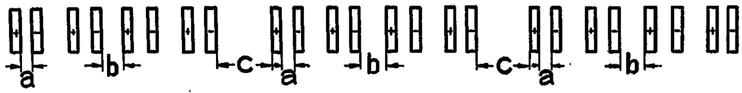


Fig. 10. Furnace leads.

a higher test pressure than twice the working voltage + 10,000 volts. In such cases the tappings are arranged in a special way for reducing the highest voltages which can occur. This is commonly managed by dividing the HT winding into two parts (fig. 7 c) or more (fig. 7 d) these parts being electrically separated and connection between them being effected outside the transformer by extra terminals. At the outer points (A—B) of the winding there thus always exists the normal working voltage. The highest pressure difference arising is thus equal to the working voltage if the ratio of the change is less than 1:2 or the working voltage multiplied by half the change if this is greater than two. If the winding is further divided the reduction in voltage is still greater. As an example of the way in which the connections can be made in order to reduce the highest pressure difference we may refer to the scheme shown in figs. 7d and 8. (Fig. 8 shows how the transformer and the winding coupler belonging to it are connected together in such a case). These apply to a single phase transformer of 1,000 kVA 12,500/50—180 volts with additional tappings on the HT side for regulating the secondary voltage between the voltages given above in equal steps each of 10 %. If this transformer were arranged, as in fig. 7a, then a secondary voltage of 180 volts would mean a maximum pressure of 45,000 volts being maintained on the HT windings. If the HT windings are in two parts as in fig. 7c the maximum pressure would be 32,500 volts with 180 volts on the secondary side. As actually constructed the maximum pressure has been reduced to 20,000 volts. This transformer is accordingly built as a 20 kV transformer as regards insulation although for use on a working voltage of 12,500 volts only.

Systems of Pressure Regulation.

For regulating the voltage it has been previously said that extra tappings are arranged on the high tension side of the transformer for reconnection outside the transformer. The reconnecting can be done with the transformer disconnected from the supply by means of ordinary knife switches or other arrangements or during working by the help of our winding coupler type UR, which was developed a very long time ago. The last arrangement, *i. e.* a transformer with extra tappings on the high tension winding combined with a coupler of type UR appears to us to be the most suitable for furnace work, as on account of its simplicity it is very dependable in action and easily operated by hand. Another system which we have made use of several times in the past is to use two transformers both without extra tappings, one (the main transformer) furnished for the mean voltage required by the furnace and the other (the booster transformer)

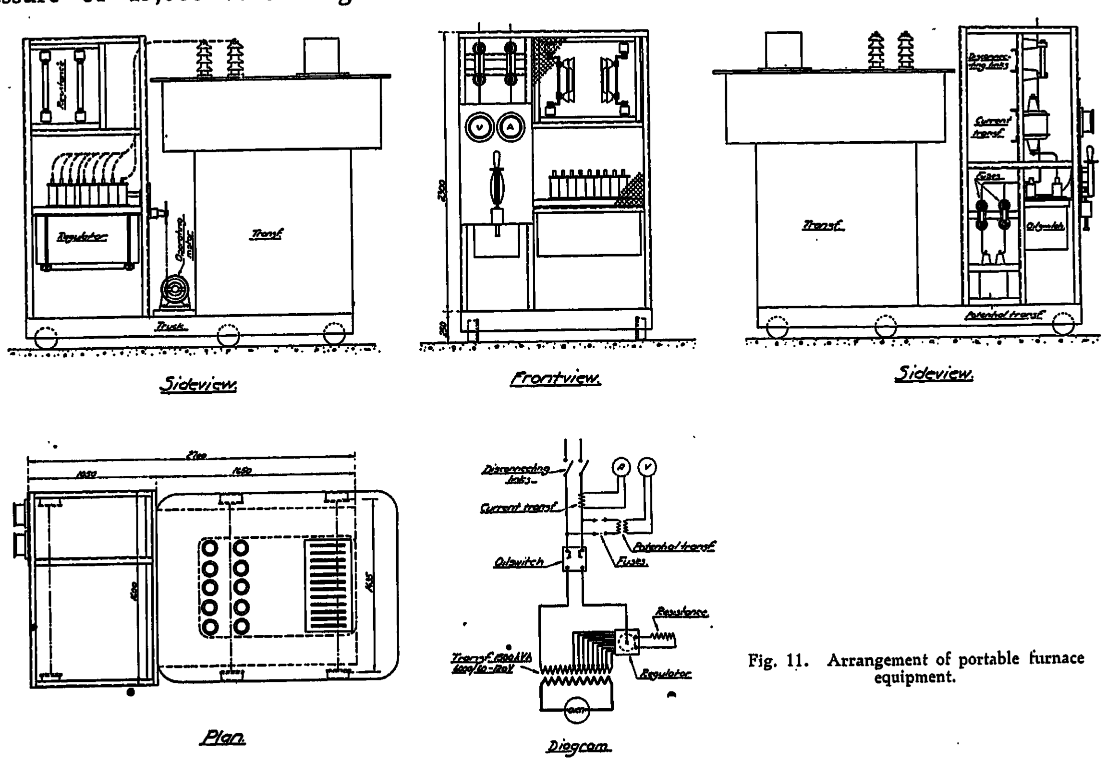


Fig. 11. Arrangement of portable furnace equipment.

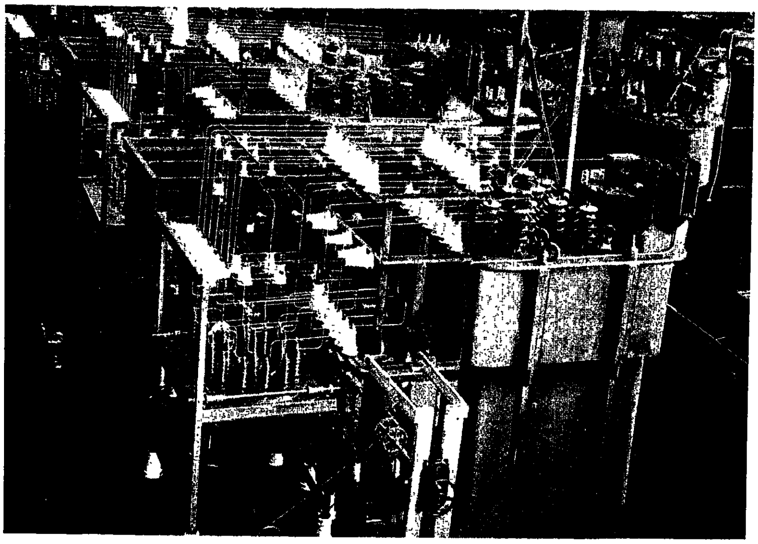


Fig. 12. Portable electric equipment for 1,000 kVA, single phase 12,500/50—180 volts, 25 cycles.

furnished for a voltage equal to the required pressure step and connected in series with the main transformer on the secondary side. By connecting the booster transformer voltage in series or in opposition to that of the main transformer and by short circuiting its high tension winding three regulating steps are obtained. This system besides complicating the layout of the plant also has the disadvantage that it can only be arranged for three regulating steps and for every additional pair of regulating steps a further booster transformer is required with necessary connecting device etc. Also when connecting the booster transformer in opposition power circulates between the main transformer and the booster transformer and causes unnecessary losses. Another system of voltage regulation which has come into use in America combines extra tappings on the transformer and a coupler similar to that in use with our system but includes also a booster transformer and an induction regulator. We cannot enter here into a more detailed explanation of this system but must point out that in accordance with our experience, obtained from installations furnished by us, a continuous regulation of the voltage is not at all necessary because the resistance of a furnace is by no means constant. In most practical cases only 2 or 3 voltage steps are used, even if the transformer is furnished with a very considerable range of regulation. The provision of a booster transformer and induction regulator must accordingly be considered as an unnecessary complication which lowers the safety of the plant in use, particularly as an induction regulator can never be built as safely as an ordinary transformer.

Division of Load.

Besides great dependability, and good efficiency an electric furnace plant must possess a number of other characteristics regarding which a few words will be said next. In the first place comes the question of the division of the load on the network and at the electrodes if 2 or more electrodes are used. In most cases the electrical power for smelting is taken from a three phase system which must be loaded as far as possible symmetrically in order that the furnace shall not upset other plant connected to the network. One single phase furnace only could not be constructed so as to give an even load on a 3-phase system. However booster transformers are connected there always remains a single phase load on the 3-phase supply. If the number of single phase furnaces is even, or if 2-phase furnaces are used the transformers belonging to them can be Scott-connected, so that when the loads on both furnaces are equal a fully sym-

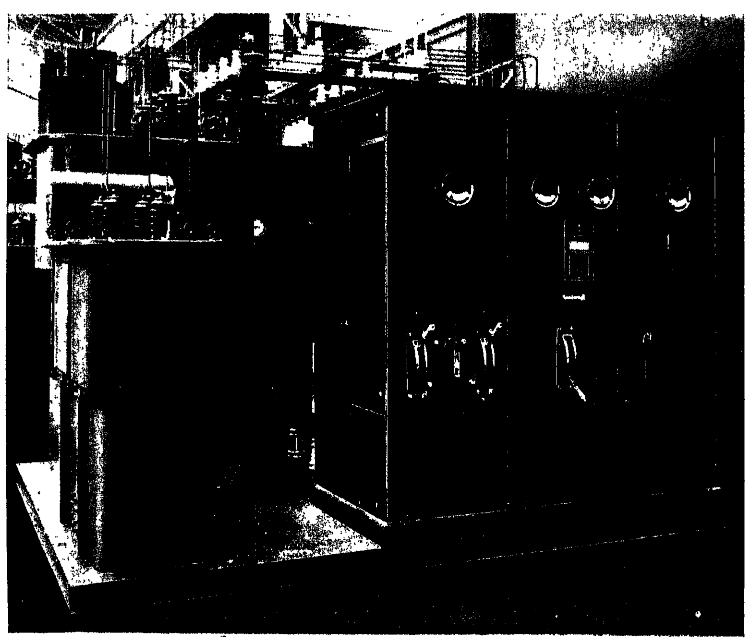


Fig. 13. Portable electric equipment for 1,000 kVA, single phase 12,500/50—180 volts, 25 cycles.

metrical load is obtained on the three phase system. If the furnaces number more than two their transformers can be single phase transformers and when suitable each transformer can be connected between two phases. In that case however it often happens that one of the furnaces must be taken out of use while the others remain at work. This results in the balance of the 3-phase load being upset unless the remaining transformers can be Scott-connected. This however is quite easily arranged and we have developed a system in which by only throwing over a 3-pole two-way switch any transformer can be connected and the remaining ones coupled in Scott-connection. The arrangement is in accordance with the diagram in fig. 9 which also shows how the change over switch should be operated by different combinations of the transformers. If the single phase furnaces number more than 3 they can always be divided up into 3-phase and 2-phase groups and it is accordingly quite easy to maintain a good loading of the 3 phase supply. If the furnace is 3-phase or multi-phase (3, 4, 6, 8, or 9 electrodes) 3-phase or Scott-connected transformers can always be used for maintaining a good division of load on the 3-phase network.

Another division of the power which is probably of even greater importance is the dividing of the energy supplied to the electrodes when these number two or more, so that all the electrodes are used up to the same extent. This not only depends on the manner in which the electrodes are arranged, but also still more upon the reactance in the different phases, and a good division of the power is obtained from the simple principle that all reactance should be as far as possible equally divided between the different phases. As the impedance of the arc is practically free from induction most of the reactance in the installation is to be found in the transformer leads and in the extra reactance coils connected in circuit. The transformers must have the same reactance per phase if they are of single-phase or three-phase type. If they are Scott-connected the main transformer should if possible possess a reactance double that of the secondary transformer (each half of the main transformer should have the same reactance as the secondary transformer). The leads to the furnace should be carried out with each phase run separately, and with the out and return conductors laminated right up to the furnace and as near to the electrodes as possible. This means that in a three phase system the secondary must always be connected in delta or open three phase. Accordingly in fig. 10, which shows a set of leads to a three phase furnace, group 1 combines out and return leads for phase 1. Group 2 the same for phase 2 and group 3 the same for phase 3. In each group the distance "a" between leads belonging to the same coil is small in relation to the distance "b" between the leads belonging to two neighbouring coils. Lastly the distance "c" between respective groups should be as large as possible in relation to the other distances. By making the conductors as far as possible of the same length and by adopting the arrangement above the reactance for the respective pairs of leads is made as nearly as possible the same and the mutual induction between the respective pairs of conductors and between the respective phases is also as small as possible, so that the smallest possible losses take place, due to transformer effect between the different groups of conductors from the windings. In ordinary cases the chief reason for the electrodes not receiving equal amounts of power is to be found in this law efficiency transformer action from one group of coils to the other.

Extra Reactance.

In cases where sufficient reactance for stable working of the furnace does not exist in the transformers, and in the furnace conductors, extra reactance coils must be introduced and care must be taken that these supply a symmetrical increase in the reactance to all phases, (three phase even with Scott-connected transformers) and that they give the required reactance with the smallest possible losses and for the least cost. The first requirement depends on the necessity of maintaining a symmetrical load on the three phase net and heavy unsymmetrical reactance connected in circuit interferes with this. Both requirements are met if one or two 3-phase reactance coils, (or three or alternatively 6 single phase coils) are connected in pairs with the primary windings of the transformer, *i. e.* between the net and the furnace transformers. It is self evident that the first requirement is fulfilled for the above and the second requirement is also met, because the primary current of the transformer is always very small in comparison with the secondary current, and a reactance coil of large current carrying capacity is more expensive and has higher losses than a reactance coil of similar capacity for lower currents (assuming that the working voltage in this last coil is not specially high). Another advantage which is obtained by this arrangement is also that the furnace transformer does not have to deal with the active power and can accordingly be smaller and have a higher efficiency.

If the reactance of the extra coil is required to be variable this can be attained by combining

two reactance coils of different capacity which are connected in series and of which either one or the other, or both, can be short circuited, or alternatively by providing a reactance coil with tappings for one or more different reactances, the change from one tapping to the other being made without breaking the current, simply by connecting on to one tapping before breaking the connection with the other. It should be noted that with this method of altering the connections the change must be made rapidly as an extra leakage field is caused which passes through the tank.

Cooling.

As regard cooling of furnace transformers the same principles as for ordinary power transformers can in general be used although forced cooling can more often be made use of for furnace transformers. This is because during working there are always men available who can attent to the colling arrangements.

Standard Accessories.

Our furnace transformers are usually provided with transport wheels with barring gear, contact thermometers which give the maximum temperature of the oil, and indicating arrangements for the cooling water which operate if there is a stoppage of the water flow in any of the cooling tubes. They are not normally provided with expansion vessels on account of the difficulty of making oil tight joints round the secondary terminals. In one or two cases furnace transformers have been provided with expansion vessels and the arrangement adopted has been found entirely satisfactory, so that where expansion vessels are considered necessary on account of high working voltage they can be fitted.

Portable Equipments.

In order that a furnace may work as safely as possible without interruption it is necessary for the electrical equipment in case a fault develops to be quickly repaired, or replaced by a spare equipment, or changed over with the equipment, from another furnace which is not in use. In plants where a large amount of voltage regulation is provided this changing gives rise to great difficulty as the connections between the furnace, the transformer and the regulating arrangements and switchgear etc. are relatively complicated and require considerable time for dismantling. In order to simplify the changing and removal of faulty parts the whole of the electrical equipment is sometimes made portable. We have developed a number of designs for such installations and several of these have been built. The furnace equipment consists in these cases of a fixed unit, the furnace with the furnace leads, operating devices etc.; a removable unit including the transformer, the winding reconnecter, reactance coils, circuit breaker, disconnecting links etc.; and a connecting unit carrying the connecting leads between the furnace and the transformer, between the incoming primary supply and the circuit breaker, and between the operating device and the winding connecters, circuit breakers etc. worked by them. The movable unit is erected upon a truck and can accordingly be shifted without making any alterations to the connections between the respective apparatus. Figs. 11, 12 and 13 show different arrangement of this movable unit. The connecting unit is so designed that all the connections can be quickly broken and so that the fixed and moving units correspond exactly with each other.

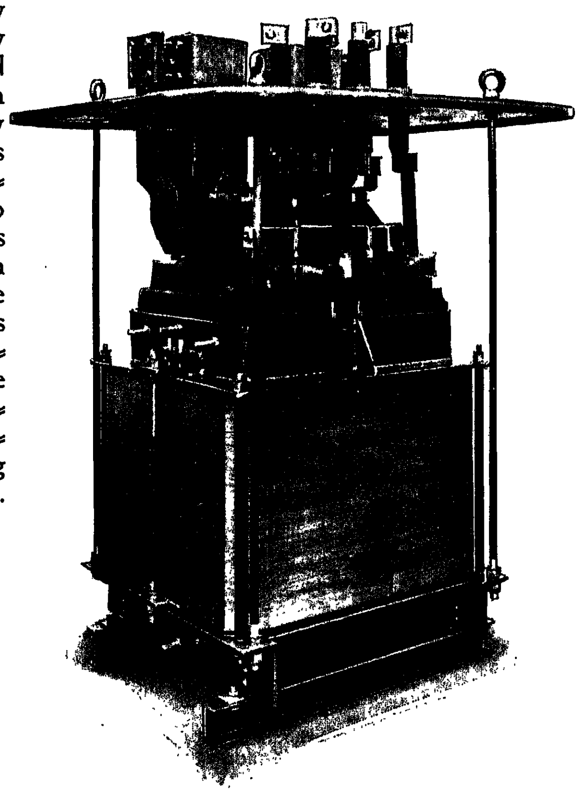


Fig. 14. 900 kVA furnace transformer for 500/55—50 volts, 50 cycles, Scott connected. Overlapping joints

TRANSFORMER OIL.

The importance of transformer oil as an insulating medium in high voltage apparatus is universally recognized on account of its high dielectric strength, low dielectric loss, high insulation resistance, and good cooling qualities.

The transformer oils have, however, the serious disadvantage of deteriorating rapidly at high temperatures, and in this respect are inferior to most other good insulating materials. The deterioration is mainly an oxidizing process, which is still further accelerated by the metals present in a transformer.

Under the influence of all these causes even the best refined transformer oil is sooner or later destroyed at the temperatures allowed in transformers. The oxidizing process forms acid products soluble in oil and acid as well as neutral resinous compounds and asphalts, of which the former are partly soluble in hot oil, whereas the latter are insoluble.

These insoluble substances form the well known sludge deposits on windings and cooling tubes — on the latter chiefly the resinous compounds soluble in hot oil — which impede the cooling of the windings and also impair the heat conduction from the oil to the cooling medium. To this is added an increase in viscosity, which makes the cooling still poorer.

Under the heading above the results of some researches performed in the Asea laboratories will be published in this journal, covering the properties of transformer oils in these respects. This article deals with studies on the effect of the electric field and on the influence of temperature on the stability of transformer oils.

As a result of these researches a new testing method is proposed, in which the combined effect of oxygen, copper, iron, and the electric field is taken into account.

I. *The influence at high temperatures of an electric field in the presence of copper and iron, and with free access of air to the hot surface of the oil.*

Knowing the effect, mentioned in the introduction, of metals and of various conditions existing in transformers, it seemed natural to expect a similar effect from the rather strong electric field to which the oil in a transformer is exposed.

Certain observations made in transformers shortly after the sludge formation has started are in favour of this assumption. In some cases it has been found that the sludge formation is more marked on the terminal leads, and those parts of the winding where the strongest electric field is present, than on other parts of the transformer.

The average stress in the oil close to these most highly stressed parts is generally in the neighbourhood of 10 kV per cm.

The following experiment was made to study this question:

Arrangement of test.

The oil was kept in cylindrical porcelain pots, on the outside covered with a tin foil coating connected to ground. In the pots were placed spirals of edgewise wound iron strips (0.15 % C rolled steel) braced with copper wire, which at the same time served as a high tension lead.

The area of the iron strips was 114 cm^2, and of the copper bracings 12 cm^2. The complete arrangement is shown in fig. 1.

The oil in the pots was thus exposed to the effect of the electric field between the tin foil coating and the spiral, where a voltage of 25 kV was continuously applied. This gives an average stress in the oil of the same magnitude

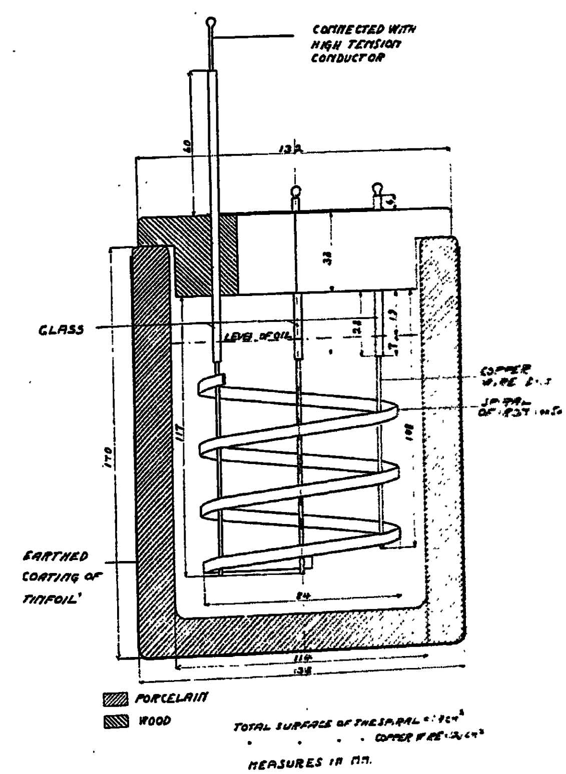


Fig. 1.

as that normally existing at the most highly stressed parts in a transformer, as mentioned above.

Even in the dark room, no corona could be discovered on the sharp edges of the spirals or around the parts of the bracings above the oil. As a further safeguard against undue effects from the possible formation of ozone, the bracings were surrounded by glass tubes reaching from beneath the surface of the oil up through the cover.

The covers protected the oil from dust, but did not prevent air circulation.

In the experiment 6 such cylinders were used each with a capacity of 1 litre. Four of these were exposed to the voltage stated above during the whole time of the test while the remaining two were not subjected to any electrical pressure, although otherwise arranged and fitted up in exactly the same manner.

The pots were all immersed in an oil bath maintained at a temperature of 90°.

The duration of the test was 6 months.

The oil used was an American oil of a well known brand, with an unusually high tar value for its kind, namely 0.21—0.22 according to the Kissling test but entirely without formation of sludge; its serial number is G. 374.

Result.

On opening the cylinders at the end of the experiment the oil was found to have undergone considerable deterioration as follows:

Oil under the influence of electric field with presence of copper and iron:

Exceedingly heavy sludge formation in the oil, a 1 mm thick layer being deposited over the whole spiral; at points where the copper joined the iron this layer increased to 3 mm in thickness. On the porcelain walls a 1 mm thick layer of rather hard deposit was also found, and similarly over the centre of the bottom of the pots with a diameter of about 30 mm (the diameter of the spiral = 82 mm); round the above was a less compact but thicker layer.

The oil was of dark brown colour throughout and was found to have a tar value of 2.45 %.

Sludge quantity, obtained after precipitation with normal benzine = 2.54 %.

Acidity of sludge = 98.8, of oil 4.9.

Oil which was only subjected to heating in the presence of copper and iron.

Heavy deposition of sludge in the oil. No deposit on the spirals except in the vicinity of the copper conductors; none on the sides of the porcelain pots. On the bottom was a loose layer 2—4 mm thick.

The oil was of dark brown colour throughout; tar value = 1.84 %.

Sludge quantity, obtained after precipitation with normal benzine = 1.1 %.

Acidity of sludge = 36.4, of oil 0.98.

This experiment thus shows the great sludge formation in a fairly good oil when heated to quite a normal working transformer temperature under the influence of an electric field in the presence of considerable masses of copper and iron and with air allowed access to the surface.

The increase in the amount of sludge through the influence of the electric field is over 100 % while the acid and soluble tar and resinous compounds are increased by 33 % above the quantity formed in the presence only of copper and iron. In addition to this the sludge formed is of an entirely different character, being found deposited on the parts under electrical pressure, in hard, tightly adhering layers, especially at the outer corners of the spiral where the potential gradient is greatest.

The acidity is 2.7 times higher in the sludge and 5 times higher in the oil.

II. *Effect of temperature on the stability of transformer oils.*

With regard to the much debated question as to what temperature is allowable for the oil in a transformer, it is of the greatest value to know the connection between the time of heating until sludging occurs, and the temperature, and above all to investigate if there is a temperature below which no sludge formation will take place, no matter how long the heating proceeds.

Method of conducting the experiment:

To obtain conditions corresponding as far as possible to those existing when an oil is used in transformers and apparatus, the heating was carried out in open rectangular containers of sheet iron, in which copper was placed. An electric field was not used on account of the complication of the arrangement. Nor were varnish and insulations used as these have been shown to be practically without influence on the sludge formation. (These experiments will be reported on later).

With a view to reducing the time of heating the containers were flat, and with the following dimensions, oil quantity, and surface area of copper:

Surface area of container	100 cm^2
Quantity of oil	100 cm^3
Area of copper (wire)...............	10 cm^2

Four such containers were prepared and placed in an electrically heated sand bath. In order to

maintain the same temperature in all the containers these were placed close to each other in a common tank of heavy sheet iron, which in its turn was sunk into the sand bath. By this means four different transformer oils, as specified below, were heated at the same time under identical conditions.

Heating was carried out with free access of air at 70, 90, 105, 120 and 150°C and the time of heating was determined, for different oils, until the first traces of deposit or turbidness were observed. This time, in what follows, is called the »critical time» of the oil.

The oil was tested every day for formation of deposit, a small quantity being removed in a test-tube after careful stirring; this oil was of course returned to the container afterwards. The examination was made by transmitted light after the oil had cooled, so that sludge soluble in warm oil was also taken into account. In doubtful cases the solubility of the oil was tested in petroleum spirit.

All the oils were filtered before use, so as to remove any turbidness existing beforehand. In addition, when turbidness was established, the tar value and oxygen content of the oil was determined.

The oils used were:

I. Extra high grade transformer oil (G. 512)
II. Best high grade transformer oil (G. 488)
III. Transformer oil I, used for some time in a transformer (G. 508)
IV. Second grade transformer oil used in a transformer for a considerable time (G. 505)

Result:

Oil	I	II	III	IV
Before heating.				
Tar value %	0.009	0.014	0.02	1.40
Tar value after oxygen treatment, %	0.10	0.20	0.30	—
Precipitate	None	Trace	Perceptible	—
Acidity as % SO_3	0	0	0	0.08
Flash point	184	162	168	146
Burning point	215	195	205	185
Viscosity of 20° in °E	5.2	2.84	3.0	8.2
Specific gravity	0.87	0.84	0.85	0.90
Freezing point	−5	−8	−8	−12
Heated to 70° C.				
Critical time, k, hours	3300	2641	2585	785
dk/dt	64.5	125	239	153
Tar value %	1.36	1.37	1.15	1.96
Acidity as % SO_3	0.06	0.07	0.06	0.09
Heated to 90° C.				
Critical time, k, hours	2064	911	597	120
dk/dt*	64.5	55.7	37.0	8.0
Tar value, %	0.44	0.44	0.42	1.84
Acidity as % SO_3	0.04	0.025	0.03	0.15
Heated to 105° C.				
Critical time, k, hours	1073	353	233	65.5
dk/dt	64.5	25.8	16.0	3.25
Tar value, %	0.54	0.38	0.38	1.80
Acidity as % SO_3	0.035	0.030	0.035	0.12
Heated to 120° C.				
Critical time, k, hours	137	65	50	17
dk/dt	52.0	9.0	5.4	1.35
Tar value, %	0.58	0.75	0.77	2.06
Acidity as % SO_3	0.04	0.05	0.055	0.10
Heated to 150° C.				
Critical time, k, hours	6	4.5	4	2.5
dk/dt	0.48	0.45	0.25	0.085
Tar value, %	0.66	1.03	0.80	2.19
Acidity, as % SO_3	0.06	0.07	0.06	0.11

It will be noticed that the derivative dk/dt is also given for the curves over the critical time, k, as a function of the temperature of heating t; these curves are given in curve group I (fig. 2.). The curve group II (fig. 3.) represents the derivatives, which show more clearly the tendency of the oil towards stabilisation.

These curves show that oils III and IV *i. e.* those which the Kissling tar formation test, and also the test in question at above 70°, showed to be the poorest ones, show the most decided tendency to stabilisation as regards sludge formation, and for these 60° would seem to be admissible as a stable temperature. For oils I and II, which came out decidedly better in the above tests, this is not the case when the low temperature of 70° is in question.

On the supposition that the established form of curve is maintained, even at lower temperatures, oil II should be stable at about 30°, while oil I would never reach a stable temperature as regards sludge formation.

It is worth noting that the oils which had been in use for some time showed special tendency to quick stability. This may possibly be explained by the fact that all oils — even the best — contain a small amount of already partly formed, resinous products soluble in oil, which are not destroyed by refining, or which are formed during the time the oil is in stock. These substances can be expected to form insoluble asphalt substances (asphalts) quickly with free access of air, even at low temperatures, by oxidation, intermolecular action, and condensation. If now an oil has been some time in use and has also undergone heating this alteration has already taken place, and the least permanent portion has been precipitated, so that such an oil would be expected to be stable at the lower temperature. Certainly during this a

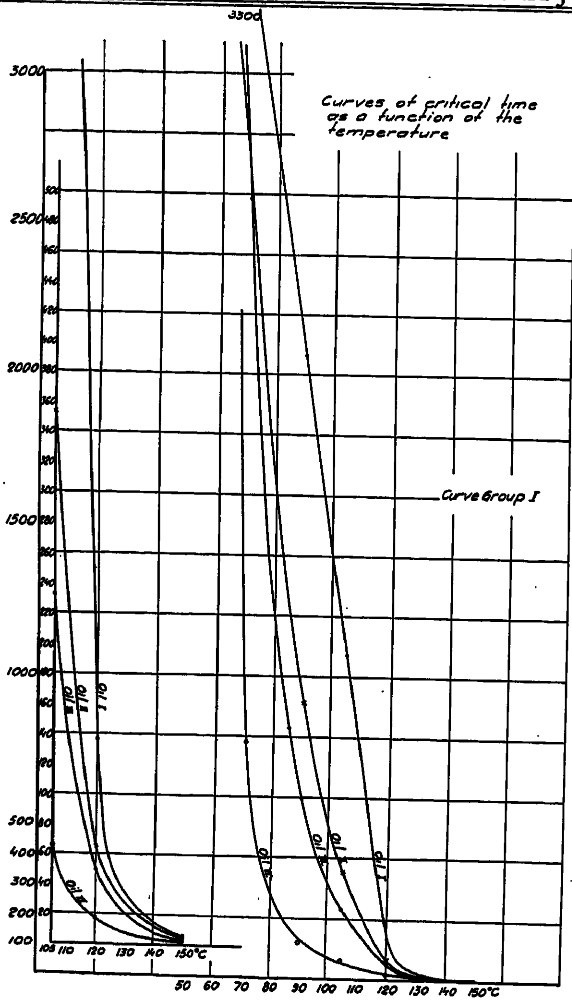


Fig. 2.

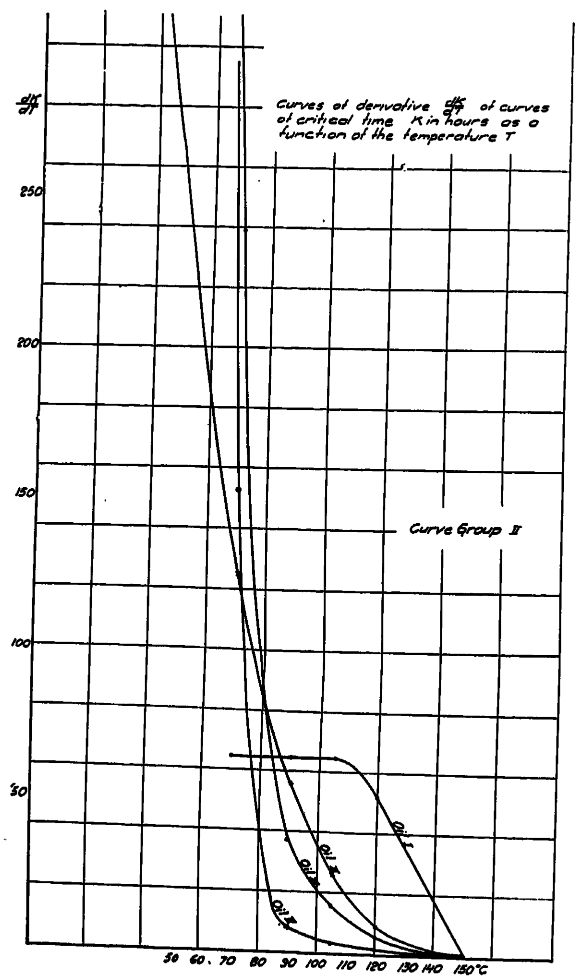


Fig. 3.

further depreciation of the oil has taken place and new resinous and acid compounds have been formed, but it is not unlikely, that these are of another character and require a higher temperature or a very long time at a low temperature for transformation into insoluble substances. The fact that oils III and II are of the same kind speaks in favour of this conclusion. A further likelihood of the above hypothesis is indicated by the extraordinary increase in the critical time for 70°, above that at 90°, for oil IV, which has the highest tar value *i. e.* the greatest amount of completely formed soluble acid products of decomposition. This is also the case with oil III, which comes next in order, both as to the question of the proportion between critical time for 70° and 90° and in tar value.

It may be mentioned further, that it was shown, that certain oils which were fairly good according to the Kissling test, developed resinous products when kept standing in stock transformers.

The hypothesis put forward above leads finally to the conclusion that formation of resinous products, which takes place in a good unused oil at low temperatures is without great significance to the good operation of transformers or other apparatus.

As the above depends entirely upon the supposition that the connection found between critical times and temperature is correctly given by the curves drawn, and still holds good even for low temperatures, a continuation of the experiment is being made for control purposes by warming oil to temperatures below 70°C.

The part of the experiment already completed clearly indicates, however, that the stable temperature is below 70°C — in the most fortunate cases at 60°C — and that the danger of sludge formation increases greatly with temperatures above 70°. This shows the importance of keeping the oil temperature as low as possible, preferably between 60° and 70°C.

On examining next the tar value, and acidity

found with different heating temperatures it is discovered that for the same oils these are highest after heating up to 70°, 120° and 150° respectively, which also indicates that the oils undergo oxidation chiefly at very low and very high temperatures. In the region of 90°—105°C the acidity and tar values are relatively low suggesting that the sludge formation at these temperatures is chiefly to be ascribed to polymerisation and condensation, while absorption of oxygen is of quite subordinate importance.

As the permanency of two oils against polymerisation, condensation and oxidation can, of course, vary according to the constitution and degree of saturation of the hydrocarbons contained therein, it is evident that the dependence of the sludge formation of temperature can exhibit wide dissimilarity and their heat-permanency curves may intersect.

Finally it should be pointed out, that the critical time of an oil can not be regarded as the only deciding factor in regard to its value as a transformer oil. Other investigations — to be published later — have shown that different oils behave very differently after sludge formation has started. The amount of sludge formed during a certain time is very different for oils of different origin and refinement, in spite of similar values of the critical time.

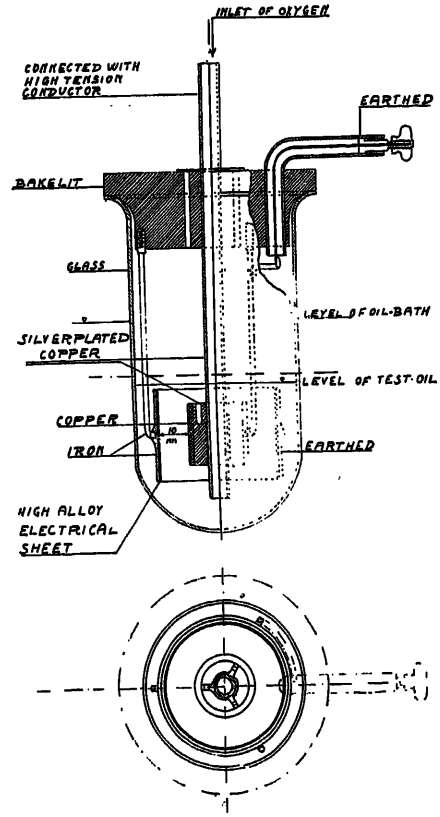


Fig. 4.

III. *A new method of testing the quality of an oil in regard to durability against heating in transformers and apparatus.*

The lack of agreement between various methods of testing the quality of an oil is probably generally recognized. This is quite evident on account of the great differences in regard to temperature, presence of substances affecting the sludge formation, the treatment in general, and methods for determining the quantity of products formed.

This new method is based upon the requirement that no consideration should be given to arbitrarily chosen reactive substances or products, and on the contention that it is incorrect to judge the oil after an arbitrarily chosen time of action.

Since the methods of refining generally are arranged to make the oil as stable as possible against the treatment given and the substances present in the test, it has been required from this new test, that all substances and conditions usually present in transformers, which can be shown to have an appreciable effect on the oil, should also be included in the test. Otherwise special types of oil are likely to appear, which may pass the test but nevertheless fail to give satisfactory results in practice. For instance, the test includes common stoft steel as well as silicon steel, since iron has been shown to accelerate considerably the sludge formation, although not to the same extent as copper. Iron soap has also been shown to be present in the sludge formed under the influence of an electric field (according to I). A great influence of such soaps is found.

The test is performed under the influence of an electric field with an average density of 10 kV per cm.

The heating temperature has been fixed at 100°C, which is only slightly above the maximum temperature for transformer oil allowed in the standardization rules of certain countries. To go higher than 100° was not considered safe.

Finally it should be mentioned that a certain quantity of oxygen (1 litre per hour and 60 gr. of oil) is blown through the oil. The oxygen is dried and purified in passing through concentrated sulphuric acid and slaked lime in succession.

The heating takes place in an oil bath, reaching a certain distance above the level of the oil in the test; the temperature is controlled within ± 0.5°C with a thermostat, and a uniform temperature is maintained by means of a stirrer. Three tests are made with different heating times so adjusted that a good oil shows very

little sludge (about 0.02 %) after the shortest time (70 hrs.), but a large quantity (about 0.2 %) after the longest time (200 hrs.). With the aid of these values is plotted a curve of the sludge quantity in function of the time, showing the time required to start sludge formation (by extrapolation) as well as the increase in sludge with time.

In testing oils with known characteristics, however, only one test will be necessary, preferably with 100 hrs. heating time.

The arrangement is shown in fig. 4, which is drawn in scale 4:10.

The oxygen is admitted through the central tube, which also serves as the high voltage terminal. The tube as well as the cross carrying the smaller copper cylinder are made of silver-coated copper in order to prevent these parts having an appreciable influence upon the test. At normal voltage there is no corona on any part of the apparatus, so that all ionization or ozonization of the oxygen is excluded. Nor has corona been noticed in the oxygen bubbles passing through the oil in spite of the electric field between the two cylinders.

The inner cylinder is made of copper, the outer one of iron. The latter consists of two parts welded together, of which the inner one is of silicon steel, the outer one of soft steel (0.15 % C). The iron cylinder is grounded through the bracings.

Both cylinders can easily be removed for cleaning. Before starting a test, the copper cylinder is heated red hot and the oxide formed is reduced by alcohol; the rest of the apparatus is pickled, washed, and dried. After cleaning, to avoid oxidation, the active parts (the cylinders) should be kept in bensol until they are placed in the oil.

The sludge quantity is determined as in the Michie test: the benzine used should not contain more than 2 % aromatic hydrocarbons, and should distil over below 95°C.

It has been found necessary to wash the sludge formed once with this benzine after drying, because a slight quantity of oil is likely to adhere mechanically to the sludge. In drying, the sludge usually forms a compact mass, whereby the oil is collected on top of the sludge and can be washed away without removing any sludge. Tho check this, however the benzine used is afterwards filtered.

The sludge quantity is given as a percentage of the oil quantity.

The acidity is determined for the sludge and for the oil after removal of the sludge.

Repeated tests have been found to agree very well.

In order to avoid exaggerated influence from either one of the factors affecting the test, which might give a difference between test results and practice, it will be necessary to properly adjust the active metal surfaces and the quantity of oxygen against each other and the quantity of oil. It is intended to perform this with comparative tests in actual transformers with a number of oils differing in refinement as well as in origin.

The results of these tests will be published later, as well as studies on the influence of the strength of the electric field, of different sizes and arrangements of the cylinders, different quantities and temperatures of the oxygen, the effect of the difference in level between the oil to be tested and the oil bath, and of the heating temperature, and also tests over the increase with temperature, for different oils, of the sludge and the acidity.

A CONTINUOUS CURRENT PLANT FOR SOUTH AFRICA.

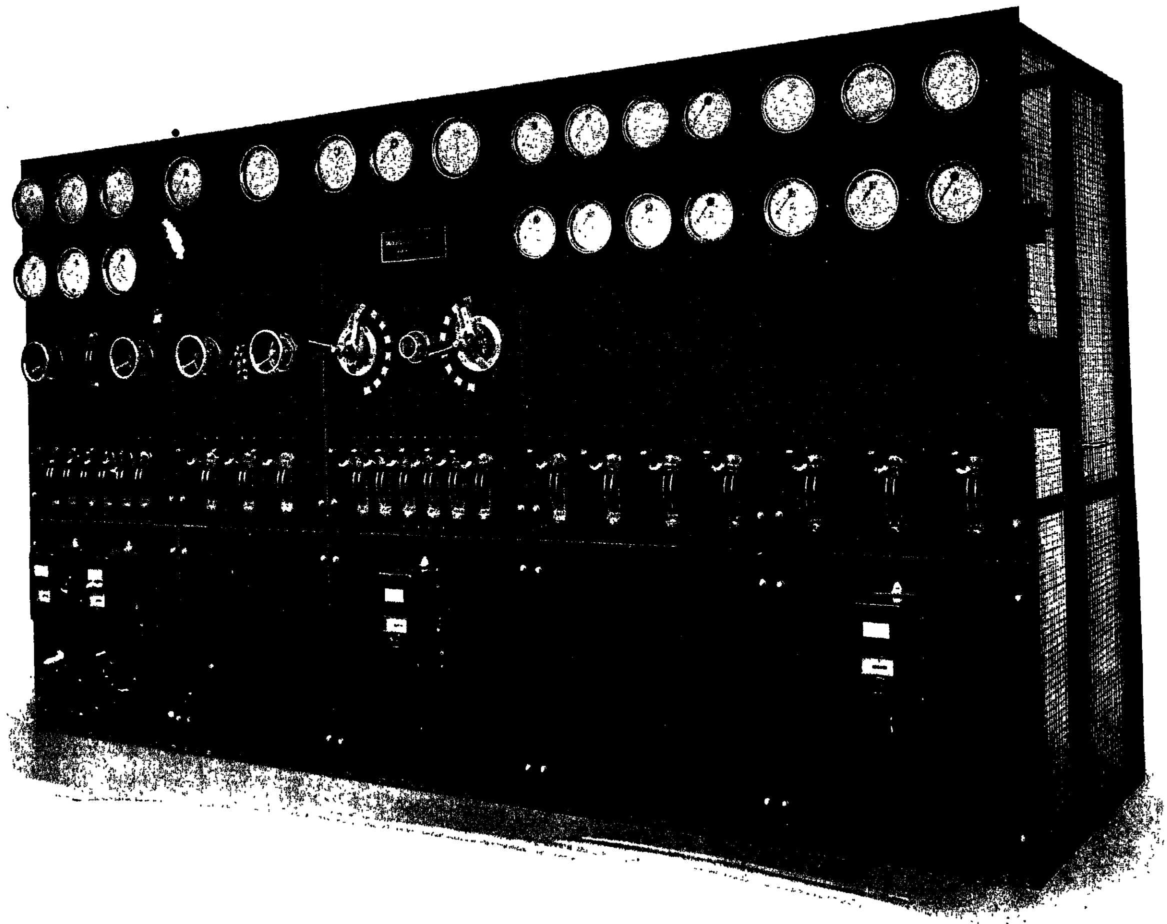


Fig. 1. Five panel switchboard of black enamelled slate. Front view.

At the beginning of May this year Asea supplied a continuous current installation to Messrs. Findlay, Durham & Brodie (agents in London for Messrs. Reunert & Lenz) for Kokstad in South Africa and as special plant had to be put in hand, which is of a very interesting nature, we give below some general particulars regarding it.

The plant delivered consists of two generators, and complete switchgear for distribution and running the generators in parallel, also a three-wire accumulator battery. The generators, which, in accordance with the customer's requirements, normally run compounded, are arranged for running in parallel and also designed for charging the battery.

Battery.

This consists of 240 cells and has a total capacity of 290 ampere-hours. The maximum charging current is 72 amperes.

Generators.

These are of type K-13 and designed for direct coupling to 60 h.p. engines. The maximum output is 40 kW at a voltage of 2×220 volts at 600 r.p.m., corresponding to a load current of 91 amperes. They are built with sliprings and three-wire compensators for a maximum of 15 % of the load current in the neutral. The series windings are arranged in two circuits as shown in the connection diagram, fig. 3.

Booster Set.

This consists of a K-9 generator for 72 amperes and 13 kW maximum output at 220 volts. The machine is shunt wound and arranged for

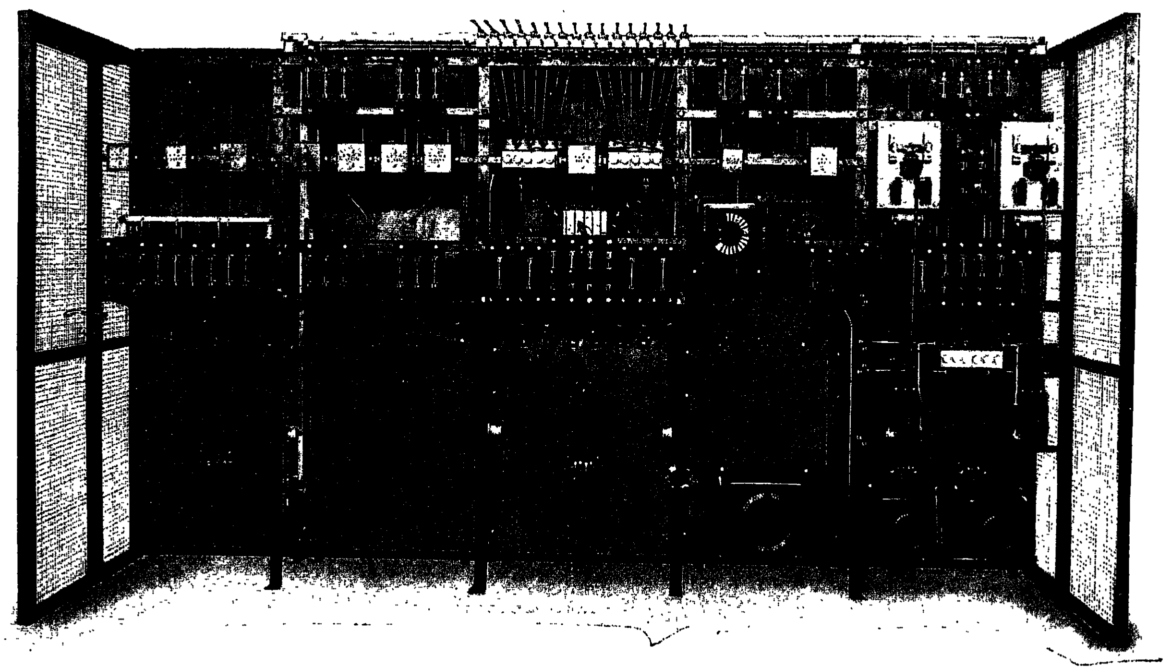


Fig. 2. Five panel switchboard. Rear view.

separate excitation at 440 volts. The voltage of this generator is arranged for regulation by resistance from 0—220 volts. The generator is direct coupled to a type K—9 shunt wound continuous current motor for 440 volts and 1,000 r.p.m.

Switchboard.

Scheme of Connections.

As the machines are normally arranged for running compounded it was necessary, when running them in parallel without the battery, to balance them by means of an equalizer. As, in this special case, the generators are arranged with the compound winding in two circuits, double equalizer bars are arranged between the machines. When running the machines in parallel it was necessary to arrange for the series windings to be cut out and for the equalizer connections to be broken at the same time. This requirement has been met by the double-pole change-over switches 9, and these are arranged for changing over without breaking circuit; the second requirement regarding the disconnection of the equalizing bars is fulfilled by the help of the 2-pole switch, 12 in the diagram. In the main circuit of the generators double-pole overload circuit breakers with reverse current relays are placed, for connecting and disconnecting the machines from the busbars. By the 2-pole knife switch 14 and the single-pole quick-break switch 13, each generator can be isolated from the busbars. In addition each generator is provided with a kWh meter, volt-meter, two ammeters, and shunt rheostat.

The charging arrangement was supplied, in accordance with the wishes of the customer, with simple cell regulator. All connections for charging the whole of the battery, or one or other half of it, are made by the two double-pole change-over knife switches which are arranged to break circuit (A and B in the connection diagram) and by this arrangement all interlocking gear has been dispensed with and complete safety still obtained against incorrect operation.

The whole battery is charged with the switch A in its upper position and during this operation it is immaterial whether switch B is closed in the upper or lower position. Discharge of either half of the battery can only take place with the switch A in its lower position. The position of the switch B then determines which half of the battery is connected.

The battery is connected to and disconnected from the busbars by 4 single-pole quick-break switches (13 in the coupling diagram).

The booster generator is protected by a minimum current release in its armature circuit (15).

In addition the switchboard is furnished with 7 outgoing three-wire circuits each provided with switch, fuses, and instruments, as shown in the diagram of connections.

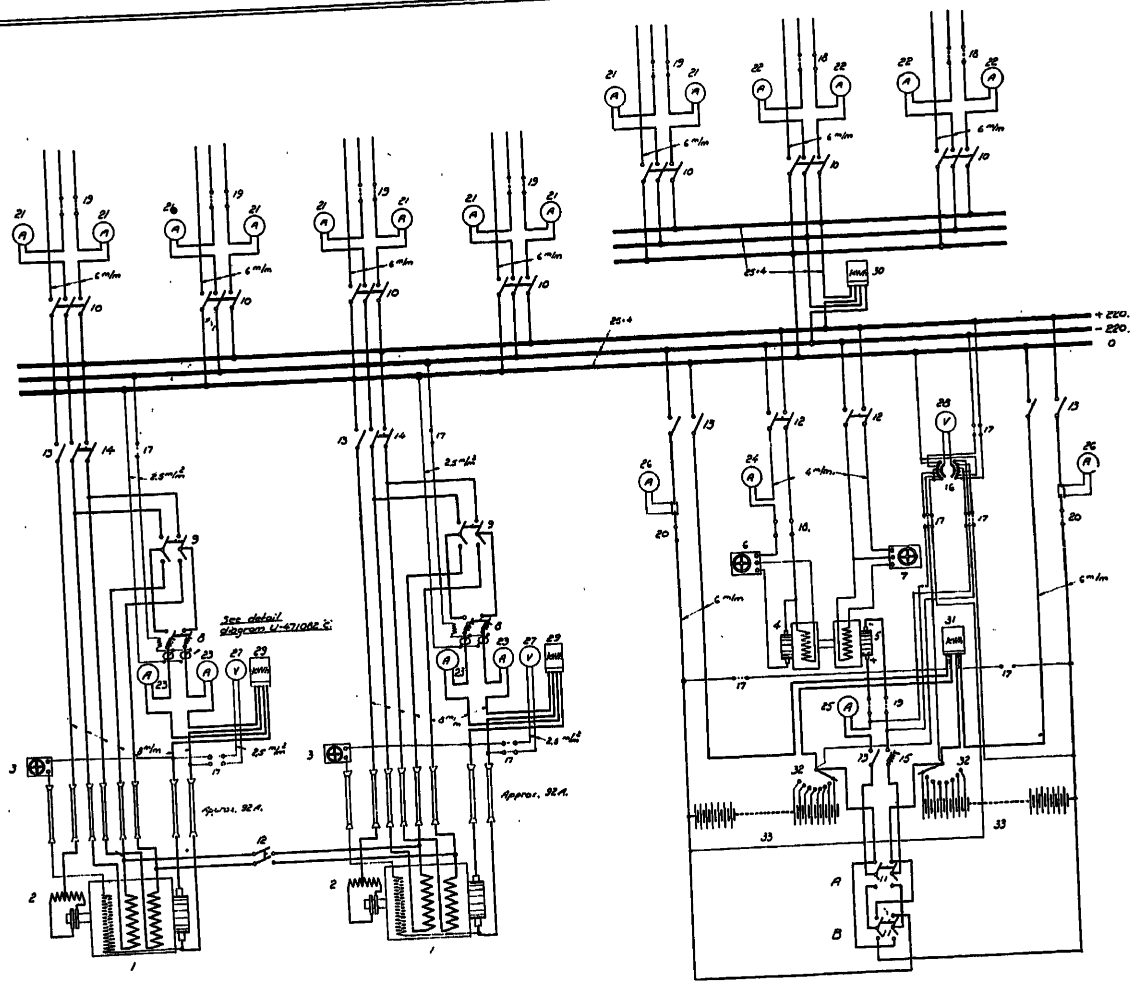


Fig. 3. Diagram of connections.

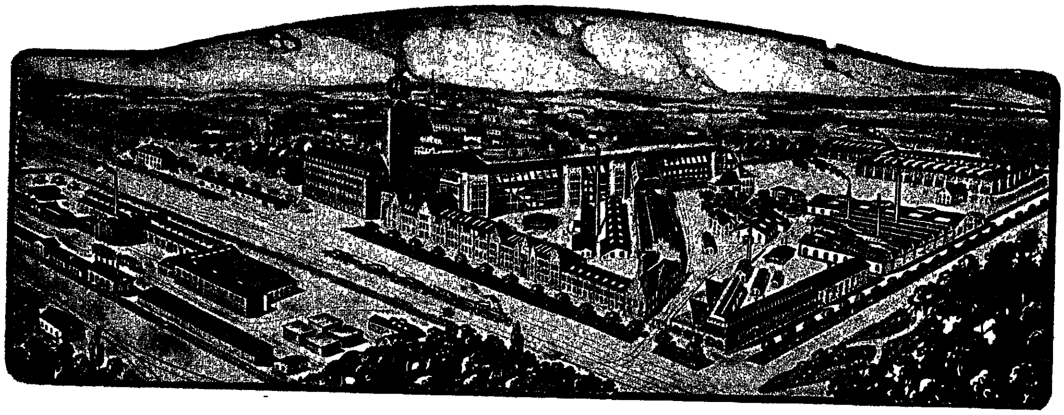
General.

As regards the appearance of the switchboard this can be gathered in a large degree from figs. 1 and 2, which show front and rear views respectively of the switchboard after erection in our shops.

The switchboard is furnished with 5 black enamelled slate panels, each having a total height of 2.4 m, and the total length of the board is 4.3 m, the last being determined by the customer's requirements.

Panel 1 carries all the instruments and apparatus for the two generators; panel 2 all apparatus for the booster set. Panel 3 is the battery panel, and panels 4 and 5 are the outgoing feeder panels.

All switches, with the exception of the generator disconnecting links (14), are operated from the front of the panels and all operating arrangements are furnished with indicating plates.



Asea's head office and works in Vesteras, Sweden.

ALLMANNA SVENSKA ELEKTRISKA A.B.

Head office: VESTERAS, SWEDEN
Works: Vesteras and Ludvika
Telegrams: Asea, Vesteras

SWEDISH GENERAL ELECTRIC LTD

5, CHANCERY LANE, LONDON
Works: Fulbourne Rd., Walthamstow
Telegrams: Autosyncro, Fleet, London

OFFICES, ASSOCIATED COMPANIES AND AGENTS:

ARGENTINA
Compañia Sudamericana SKF, Buenos Aires. Victoria 502.

AUSTRALIA
Unbehaun & Johnstone, Ltd., Perth, W. A. 383/387 Murray Street.
Unbehaun & Johnstone, Ltd., Adelaide, 100 Currie Street.
Thomas Bros. Pty, Ltd., Melbourne. 201 203 William Street.
Australectric, Ltd., Sydney, Wireless House, 97 Clarence Street.
Intercolonial Boring Co. Ltd., Brisbane, 450 460 Ann Street.

BELGIUM
Société Belge d'Electricité Asea, Bruxelles, 21 Rue Grétry.

BOLIVIA
Graham, Rowe & Co., Oruro, Alianza 581.

BRAZIL
Haupt & Co., Rio de Janeiro, Rua São Pedro 50
São Paulo, Rua Boa Vista 46.
Porto Alegre, Rua 15 de Novembre 16.

CANADA
Swedish General Electric Ltd., Toronto, Ont., 107 Duke Street.

CHILE
Graham, Rowe & Co., Valparaiso, Cochrane 825.
Santiago, Bandera 267—275.
Antofagasta, San Martin 362.

CHINA
Henry J. Moysey, Shanghai, Peking Road 64.
J. Whittall & Company Ltd, Tientsin. 15 Victoria Terrace.

DENMARK
Elektricitets Aktieselskabet Asea, Copenhagen K, Bredgade 45.

ESTHONIA
Linke, Martinson & Co., Reval, Kinga tän 10.

FINLAND
Allmänna Elektriska Aktiebolaget i Finland. Helsingfors, Citypassagen.

FRANCE
Société Française d'Electricité Asea, Paris. Boulevard Haussmann 114.

HOLLAND
Groeneveld, van der Poll & Co., Amsterdam, De Ruijterkade 41, 42.

INDIA
Ewing & Co. Ltd., Calcutta. 4, Clive Row.
The Consolidated Mills Supplies Ltd., Bombay. Yusuf Building, Churchgate Street, Fort.

JAPAN
Gadelius & Co., Tokyo, 41, Akashi-cho Tsukiji.
Kobe, 58 B, Naniwa machi.
Dairen, 45, Yu-ku, Satsumacho.

NEW ZEALAND
A. S. Paterson & Co. Ltd., Wellington, 12 Cuba Street.

NORWAY
A/S Per Kure, Norsk Motor- og Dynamofabrik, Christiania, Universitetsgate 24.

PERU
Graham, Rowe & Co., Lima. Villalta 282.

PORTUGAL
Jayme da Costa L:tda, Lisbon, 16 Rua dos Correeiros 26.

RUSSIA
Acea, Leningrad, Uliza Gogolja 7.

SOUTH-AFRICA
Reunert & Lenz, Johannesburg. Consolidated Buildings.

SPAIN
Sociedad Española de Electricidad Asea, Madrid, Calle Montalban 13.

BESIDES REPRESENTATIVES IN:

GREECE. LATVIA. MEXICO.

Vesteras 1924, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

INDEX 1925

PUBLISHED BY

ALLMANNA SVENSKA
ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

INDEX

A S

E A

ASEA-JOURNAL

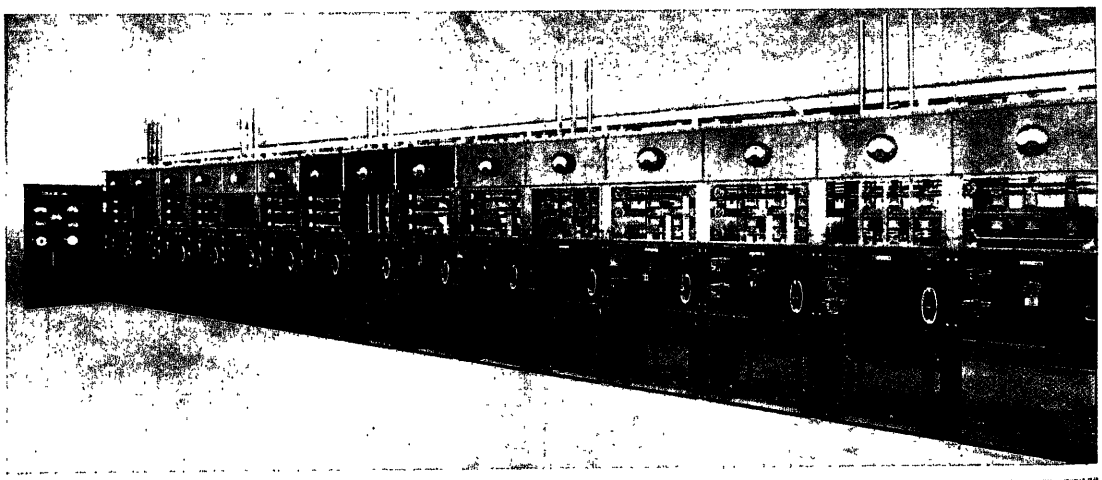
ALLMÄNNA SVENSKA
ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

VOL. II
1925

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesterås, Sweden.
Permission is given to reprint articles or extracts from this journal,
on condition that the name — Asea-Journal — is clearly stated.

JANUARY
No. 1



Low tension and high tension switchgear for Messrs. E. D. Sassoon & Co., Bombay.

AN INTERESTING INDIAN INSTALLATION.

Introduction.

In the year 1922 it was decided to bring up-to-date the drives in eight of the fifteen large mills in Bombay which are managed by the important textile firm of Messrs. E. D. Sassoon & Co. Ltd., of Bombay, Calcutta, Karachi, Manchester, London, China, etc., etc. This work was handled throughout by their Consulting Electrical and Mechanical Engineer, G. H. Thurston Esq., M. I. E. E., Am. S. M. E. of London. The fact that Asea secured the order for the greater part of the material required in competition with other leading firms is an eloquent testimonial to the high standard of Asea's manufactures, particularly as the material to be delivered had to satisfy an uncommonly exacting specification and a close inspection. The mills which are now in full operation obtain their electric power from the Andhra Valley Power Company's two stations Andhra and Tata, of which the former is of 50,000 kW and the latter of 40,000 kW the supply voltage being 100 kV. The power is transmitted, in both cases, over lines 50 miles in length, to two main substations, where it is transformed down to 22 and 6.6 kV respectively, to be afterwards distributed to the eight different mill substations, for which Asea has supplied the high tension and low tension switchgear and distribution equipment.

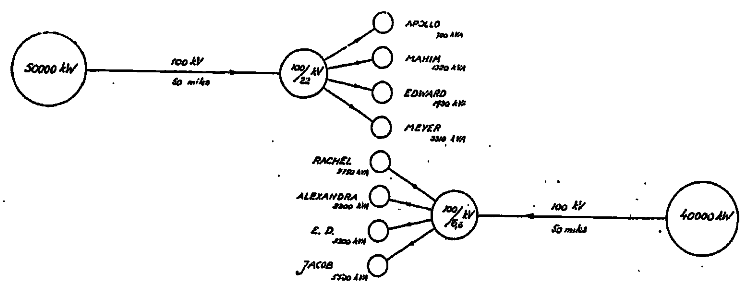


Fig. 1. Arrangement of the system.

The distribution in its entirety, from the power stations to the different transformer substations, and forward to the mill substations, is in accordance with the general scheme shown in fig. 1. Of the mill substations four, namely, "Apollo", "E. D. Sassoon Dye Works at Mahim", "Edward Sassoon" and "Meyer Sassoon" are arranged for an incoming pressure of 22 kV, while the four remaining stations, "Rachel Sassoon", "Alexandra", "E. D. Sassoon" and "Jacob Sassoon" are supplied at 6.6 kV.

From the main substations the power is taken into each mill substation by duplicate cables. Where these terminate the Power Supply Co., have provided their own switchgear consisting of disconnecting links, circuit breakers and instrument transformers for metering the power supplied.

Connection is made direct from these switchboards to the installations supplied by Asea. Before describing these in detail it may be of interest to give some tabulated particulars regarding the size of the different transformer stations with respect to the output of the transformers installed and this is given in the table below:

There is no particular difference between the arrangement of the 22 and 6.6 kV installations if the system of connecting the transformers is disregarded. For the 22 kV stations these are connected Y/Y with secondary earthed neutral point while the 6.6 kV stations are arranged D/Y also with secondary earthed neutral point. All the low tension distribution to the different mills is at 450 volts.

Plant	Number of transformers	Normal output kVA	Maximum output kVA	Voltage ratio	System of connection
Apollo Mill	1	700	770	22,000/450 V	Y/Y
E. D. Sassoon Dye Works at Mahim.	1 1	700 500	1,320	22,000/450 V	"
Edward Sassoon Mill	3 1	600 500	1,980 550	22,000/450 V 22,000/2,200V	" "
Meyer Sassoon Mill	3	700	2,310	22,000/450 V	"
Rachel Sassoon Mill	2(1spare) 1	1,000 500	2,750	6,600/450 V	Δ/Y
Alexandra Mill	2	1,000	2,200	6,600/450 V	"
E. D. Sassoon Mill	3	1,000	3,300	6,600/450 V	"
Jacob Sassoon Mill	5	1,000	5,500	6,600/450 V	"

Scheme of Connections.

Fig. 2 is a general diagram of the connections employed for the switchboards. Nearest the power supply are the main diconnecting links, placed in such a way that when they are open all the apparatus and instruments are dead. The incoming line goes from here through the main oil switch to the high tension busbars. Between these busbars and the 450 volt busbars are the power transformers, divided from the oil switch by disconnecting links on both the high tension and low tension sides. All the out-going lines are connected to the low tension busbars.

As regards the arrangements for automatic release these are of a particularly special nature

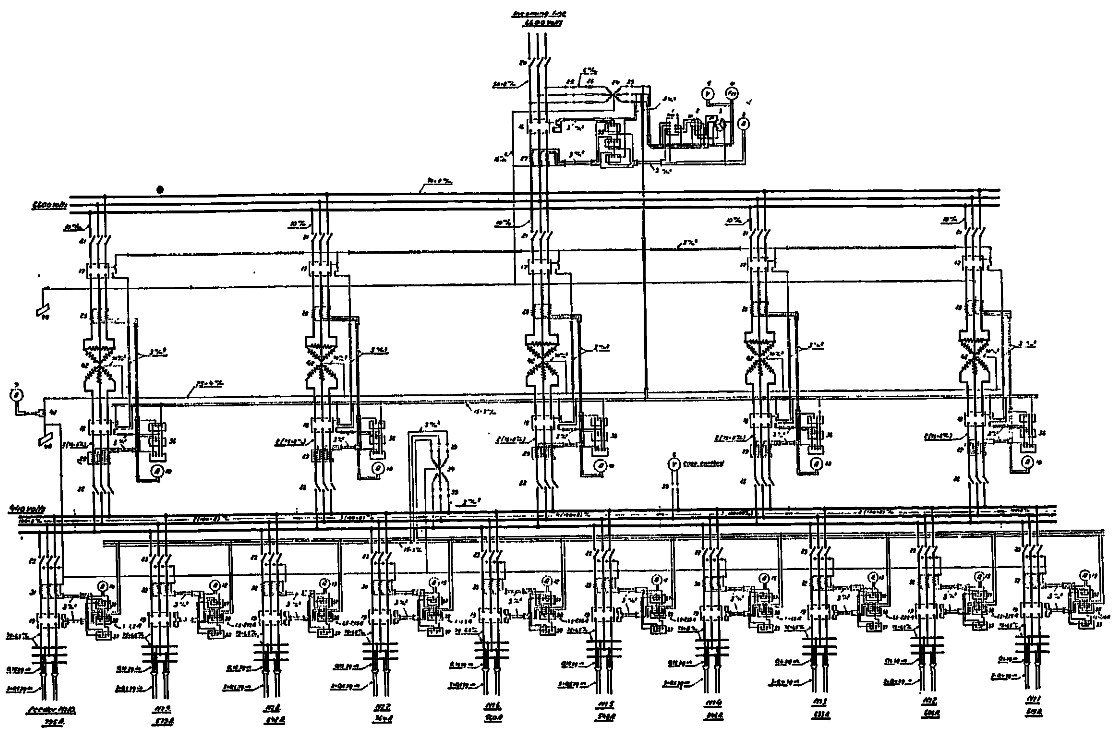


Fig. 2. Diagram of connections for Jacob Sassoon Mill.

and a full description of them may therefore be of considerable interest. The design of a system of automatic trips fulfilling the requirements in all particulars was rendered considerably more difficult by the circumstance that no supply independent of the power supply was available for releasing. The conditions of working demanded a particularly sensitive and fully selective automatic release system protecting the station equipment from every conceivable disturbance. On close investigation it was found most suitable to protect the transformers against internal breakdown only, as for instance short circuits between windings etc. By eliminating the two transformer oil switches from the system in this way great selectivity in the tripping of the oil switches in the remainder of the installation was obtained. The tripping of the transformer oil switches is accordingly done with the help of three differentially connected relays worked from six current transformers placed on opposite sides of the transformer. The three relays are adjustable for 2—10 seconds and are so arranged that they do not operate under the inequality due to the transformer's no load current. The time setting is such that with a three phase dead short circuit in a transformer the transformer oil switch must trip out before the main circuit breaker, so that in such a case the working of the remaining transformers is not interfered with. The tripping current is obtained from a three-phase potential transformer connected on the supply side of the main circuit breakers. The line oil switch is provided with a no-voltage release coil which trips the breaker either on overload or when the line voltage for any reason falls below a certain value. The current necessary for operating the release coil is obtained from the above mentioned three-phase potential transformer. On overload the current in the release coil is broken by three inverse time limit relays operated from three current transformers connected in the line. When the line voltage sinks below a fixed value corresponding to 65 volts on the secondary side of the potential transformer the circuit breaker is automatically tripped out by the minimum current in the release coil. As regards protection for all outgoing lines it was found most suitable to provide this partly by overload series release in two phases and partly by a differential release with separate potential transformers. The tripping arrangement thus consists, on each outgoing line, of three current transformers, two inverse time limit relays, and one differential relay combined with a constant time-limit relay. The circuit breakers are provided with two release coils, a series coil for overload release and a shunt coil for the differential release. The outgoing lines can, by this arrangement, be protected both against overload and against every kind of out of balance. As however, in this particular plant,

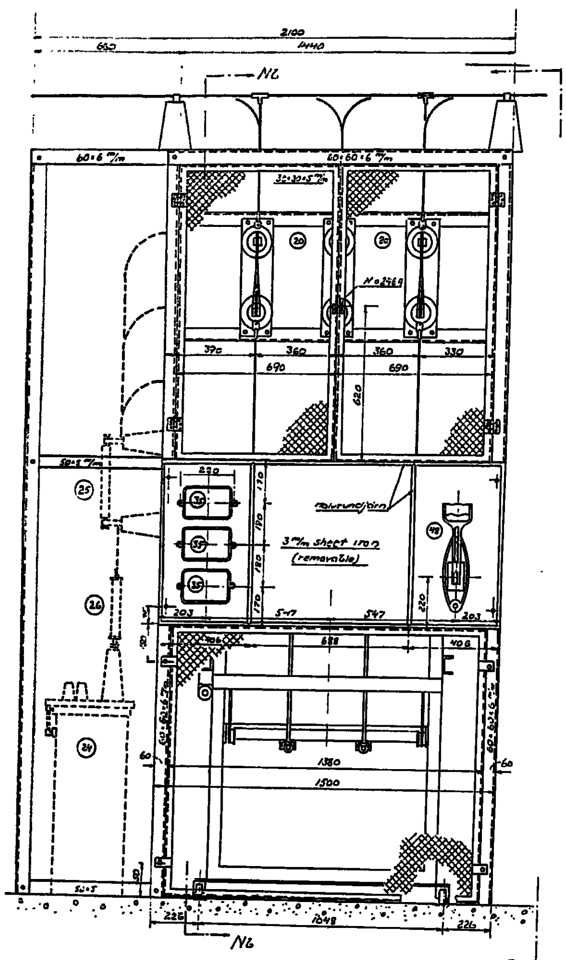


Fig. 3. Front view of 22 kV incoming line panel.

unsymmetrical releasing must not occur, except with relatively high out of balance loads, an earth current of 200 and 300 amperes respectively is permitted before release takes place. In accordance with the foregoing both transformer switches and outgoing line switch are provided with release coils excited from their respective potential transformers and these coils are so designed that they can trip the switch even if the voltage on the secondary side of the potential transformer falls from its normal value of 110 volts to 60 volts. As explained before, however, the incoming line circuit breaker is tripped out if the voltage in its release coil falls to 65 volts. By the above method it has been made certain that the protective system will operate in a satisfactory manner, even under the most unfavourable conditions.

Arrangement.

The underlying principle in the protection of this particular plant has been an endeavour to obtain:

1. Robust construction.
2. Simple arrangement of connections.
3. Easily accessible apparatus.
4. Highest possible degree of protection.
5. An arrangement of good engineering appearance in all respects.

All the switchgear is erected on self-supporting angle iron frames of a strong and simple type and all the details have been arranged with the above in view.

High tension equipment.

All the high tension equipment, including transformers, has been housed in a special high tension chamber in all transformer sub-stations. As a rule the arrangement is such that the high tension switchgear is placed against one of the longer walls of the room, while the transformers are erected against the opposite wall. The incoming line conductors are carried on wall insulators down to the line disconnecting links. For the 22 kV sub-stations these conductors are of 10 mm bare copper rod, while for the 6.6 kV substations they consist of bare copper bars. Figs. 3 and 4 show the general arrangement of such switchgear. The frame-work is made entirely self-supporting and consists of two divisions, a

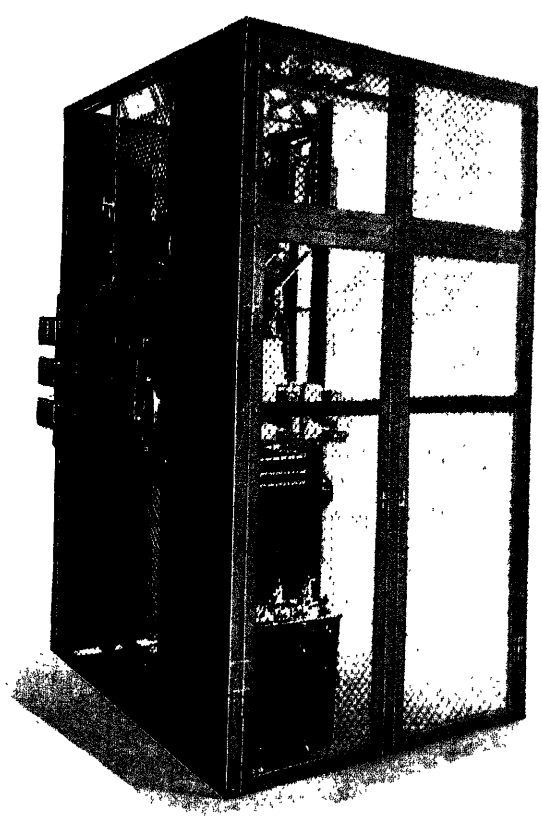


Fig. 4. View of 6.6 kV incoming line panel.

larger and a smaller of which the last contains the potential transformer with the protecting resistance and fuses belonging to it, while the larger division carries the remainder of the incoming line switchgear. All operation is done from the front. The oil switch handle and the three relays have been mounted upon a front panel of 3 mm sheet steel fixed to the frame-work with 4 screws. The disconnecting links are protected by wire mesh doors, whose locking devices can only be opened from the ground by the help of the insulated operating rod used for the disconnecting links themselves. The doors are also so placed that even when they are open it is not possible to come into contact accidentally with any of the current carrying parts. The lower part of the frame work is protected by a removable wire mesh panel, which is carried down to within 5 mm of the floor level. The part carrying the potential transformer is protected in front by sheet iron which extends to the full hight of the frame work. Access to the gear is provided by wire mesh doors with locks at the opposite sides.

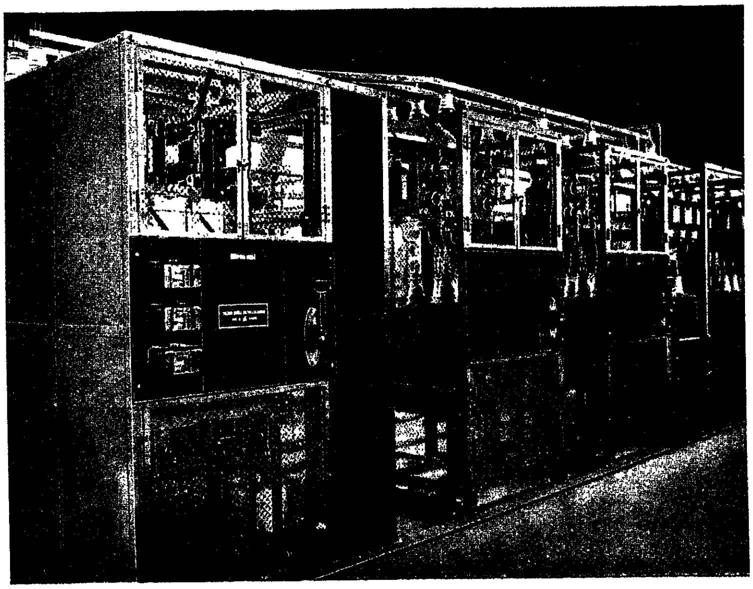


Fig. 5. Front view of feeder and transformer switchgear for 6.6 kV.

From the current transformers in the incoming line switch section conductors are carried up to the high tension busbar system. The transformer switch sections are erected alongside the incoming line switch with gangways between each, and the busbars are carried over these on strong supporting insulators, fixed to the top cross bars of the frame work of each division. The arrangement is generally in accordance with figs. 5 and 6. These sections are generally arranged in the same way as the incoming line switch section with the exeption that the division for the potential transformer is not included.

From the transformer sections conductors are carried to the respective transformers. The conductors are carried up the wall and then under the roof on supporting insulators which are carried by special iron members, the arrangement of which is in accordance with figs. 7 and 8. The arrangement has the advantage that holes need not be drilled for the insulator bolts, but the insulators, when the conductors are being erected, can be slid along the supporting iron members and no subsequent adjustment of insulators or conductors is accordingly necessary.

From the roof the conductors are led down direct to the high tension terminals of the transformers.

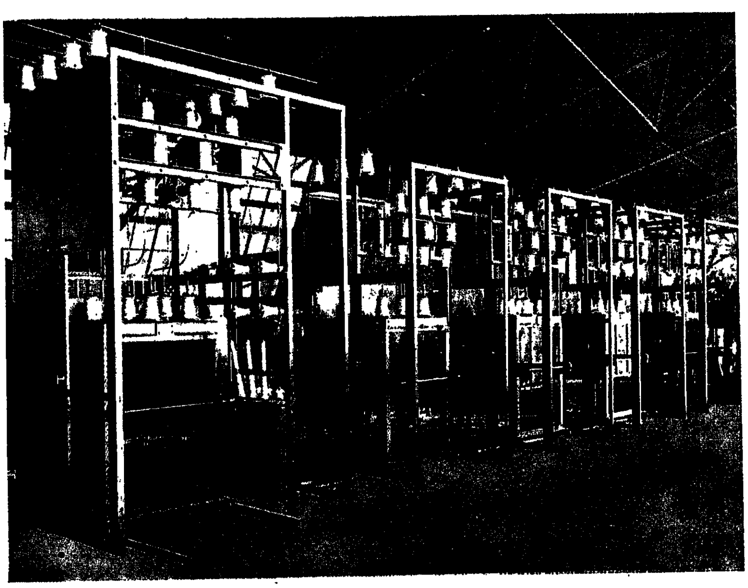


Fig. 6. Rear view of 22 kV switchgear.

Low Tension Switchgear.

The low tension switchgear is erected in a separate low tension switch-house located at the back of the transformer wall. From the low tension terminals of the transformers conductors are taken through the above mentioned wall

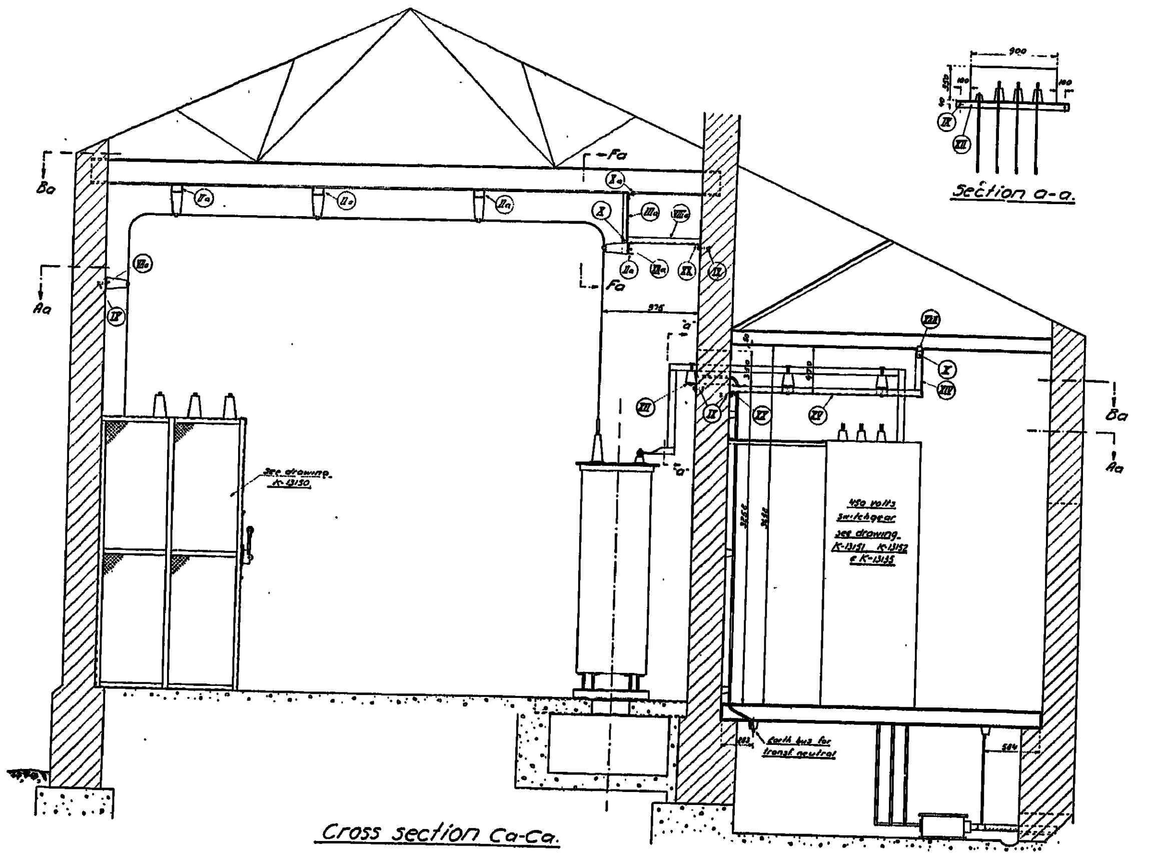


Fig. 7. Cross section through 22 kV transformer substation.

direct to the transformer sections of the low tension switchgear. The arrangement is such that these conductors run in straight lines in all the sub-stations. The transformer panels and outgoing line panels are erected together on a self-supporting framework, the general appearance of which is in accordance with figs. 9 and 10. All the sections are divided from one another by 2.5 mm sheet steel partitions which afford extremely good protection against accidental contact with current carrying parts whenever work has to be carried out in neighbouring sections.

The oil switch handles and relays are, as in the case of the high tension switchgear, mounted upon a panel in front made of 3 mm sheet steel. All sections are provided with an ammeter which is placed on a panel at the top of each cubicle. The remainder of the cubicle is protected by removable panels of wire mesh, which give good opportunities for inspecting all the apparatus. Behind the gear there is a passage 1,010 mm broad allowing both for operating the isolating links and for the removal of all oil-switches. This gangway is only accessible through a wire mesh door, which is provided with a lock. In the low tension switch-room is erected, in addition, a control panel of sheet iron which carries all the instruments necessary for providing a good and complete check on the working. This panel is, in some stations, combined with the low tension switchgear framework and in others it is entirely separate. The busbars for the low tension switchgear are carried on insulators mounted on the iron cross bars at the top of the frames. In the low tension room the flooring is of special sheet steel laid on I section girders. Under this floor there is a basement in which the cable boxes for the outgoing lines are mounted. Under the switchgear in this basement is also placed the earth conductor for the station to which is connected both the neutral points of the transformers and the lead covering of the outgoing cables. The current transformers necessary for measuring the earth current are also placed here.

Busbars.

As regards the busbar system the choice of distance between the different groups of conductors and the arrangement of these has been considered with regard to the mechanical stresses

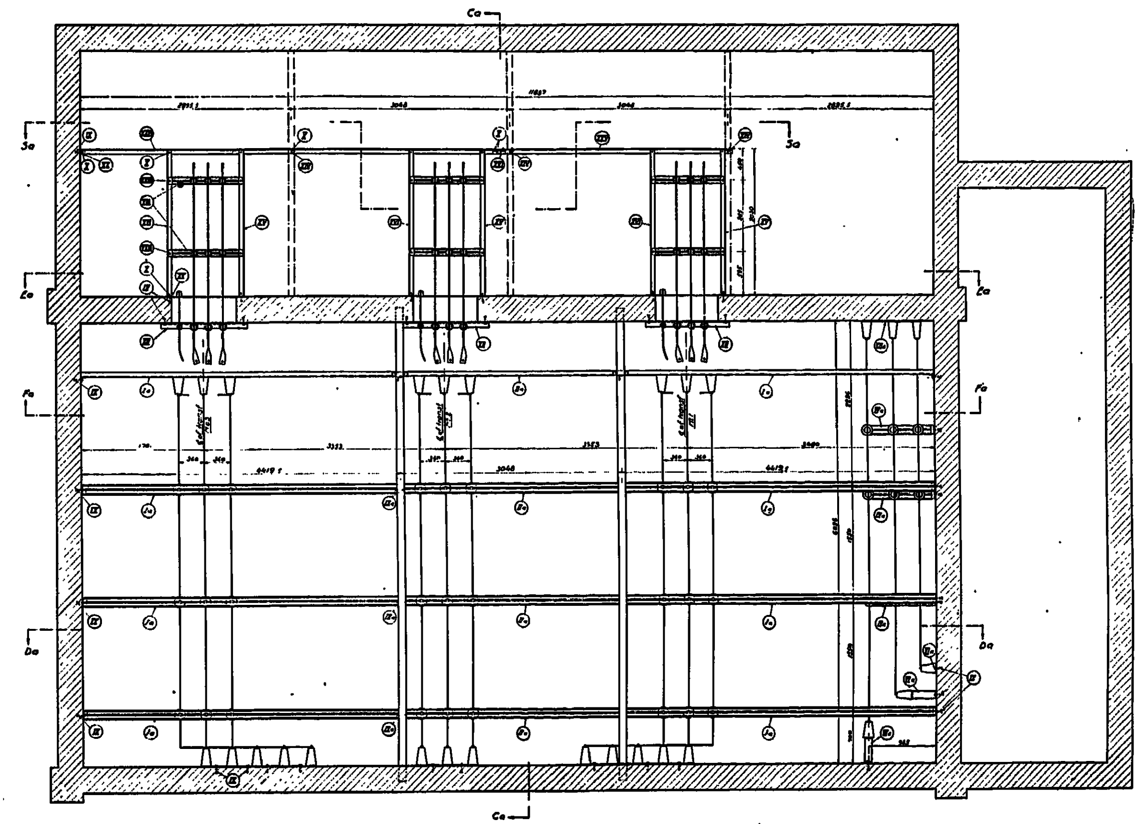


Fig. 8. Plan showing connections in 22 kV transformer substation.

arising, heating, skin effect, and the considerations of voltage drop due to induction.

Insulators.

As in the plants under consideration the power is obtained from relatively large stations, any short circuits occurring may cause very heavy mechanical stresses and this has made necessary the use of insulators of a particularly strong type.

Isolating Links.

On account of the large power to be dealt with on short circuit the isolating links are also made of a specially strong type. The insulators are constructed to withstand great mechanical stresses and the blades are provided with an extra locking device, so that they are prevented from opening if a heavy short circuit takes place. The isolating links for the outgoing 450 volt circuits are besides provided with earthing contacts for earthing the cables when any inspection has to be undertaken.

Oil Switches.

In dimensioning the oil switches also, the heavy current to be reckoned with on short circuit is a very important factor. The maximum momentary short circuit power on the 22 kV installation is reckoned to be 263,000 kVA and the corresponding continuous short circuit power to be 110,000 kVA. In consideration of the above the main switches have to be designed for breaking 250,000 kVA. With the same degree of safety the corresponding switches for the 6.6 kV swithgear have been designed with a breaking capacity of 160,000 kVA. The low tension switches have a breaking capacity of 37,000 kVA and the construction is such that the necessary factor of safety is obtained electrically, mechanically and thermally, even with the high current which occurs on dead short circuit. All switches are furnished with transport wheels and are located in their respective positions by rails set in the floor and furnished with stops which definitely determine the position of the switch in the cubicle. A simple and easily accessible rasing and lowering gear for the oil tanks permits rapid inspection of all vital parts of the switch.

With regard to the low tension switches for the outgoing 450 volt lines it was found impossible to uphold the stipulations of the spe-

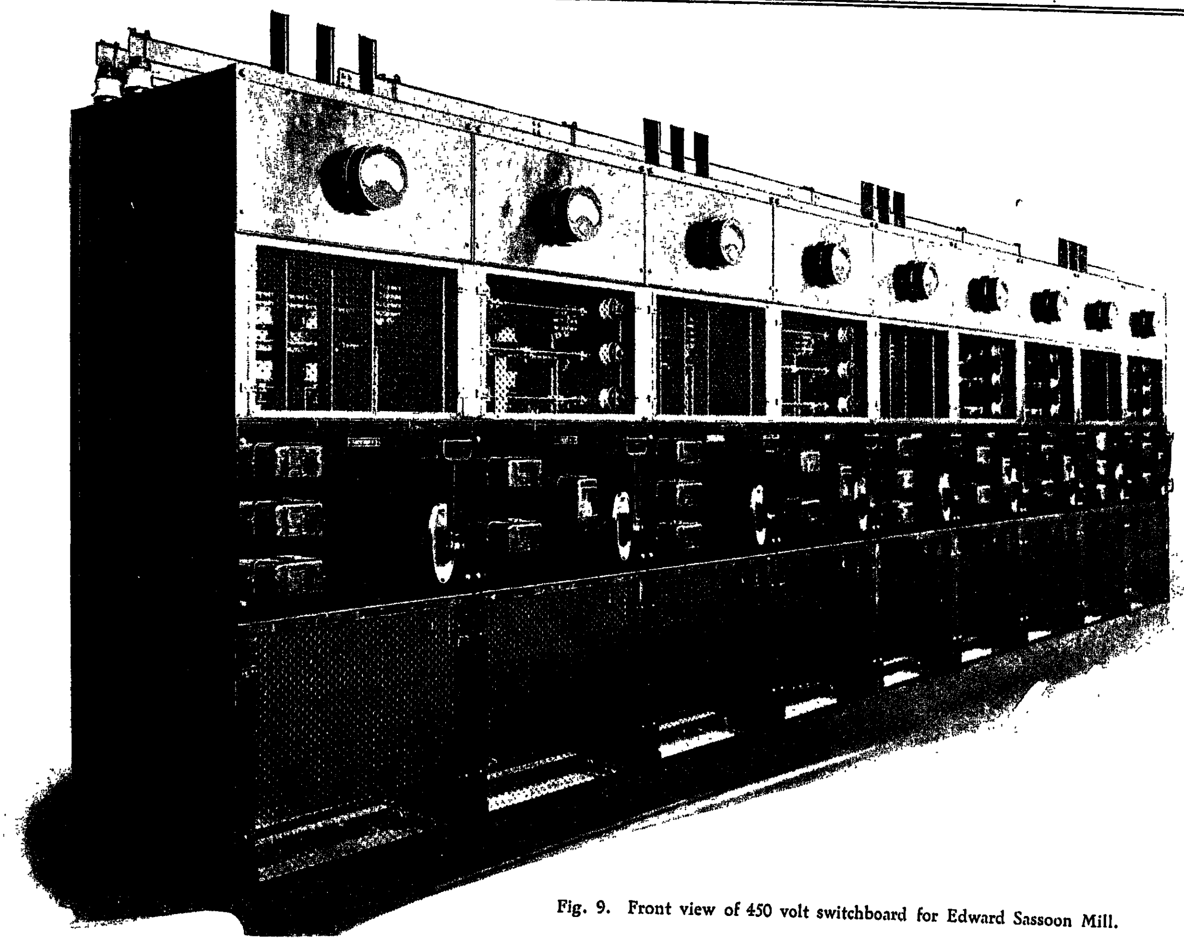


Fig. 9. Front view of 450 volt switchboard for Edward Sassoon Mill.

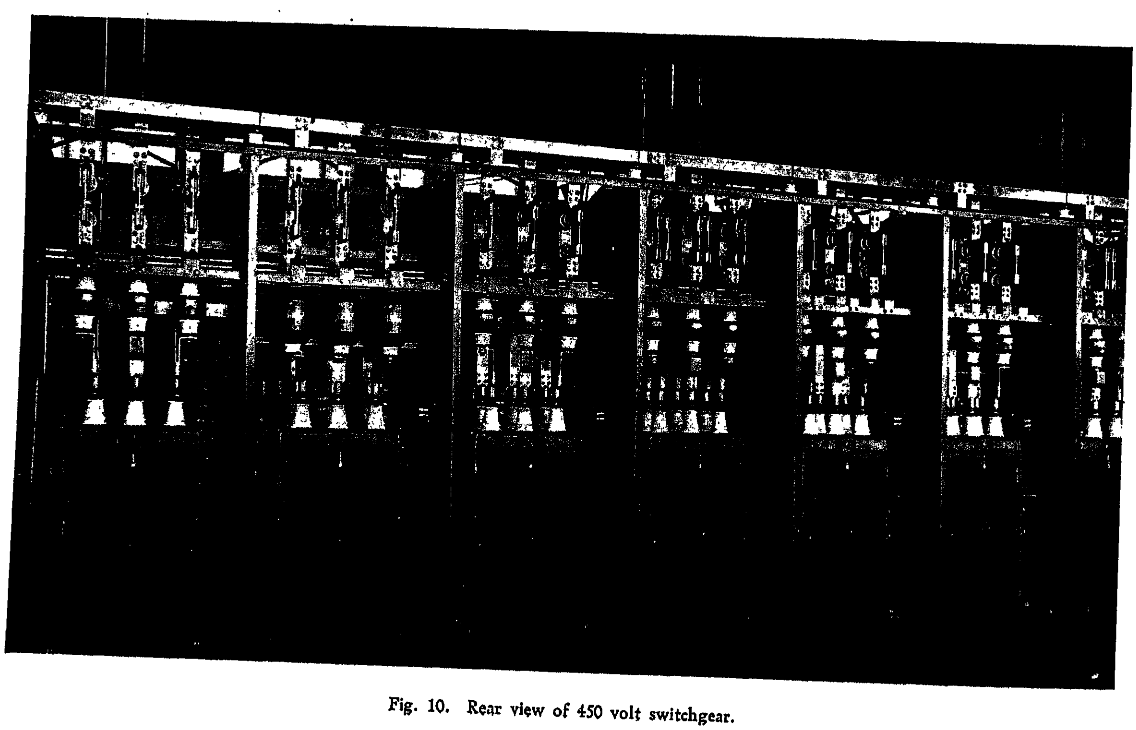


Fig. 10. Rear view of 450 volt switchgear.

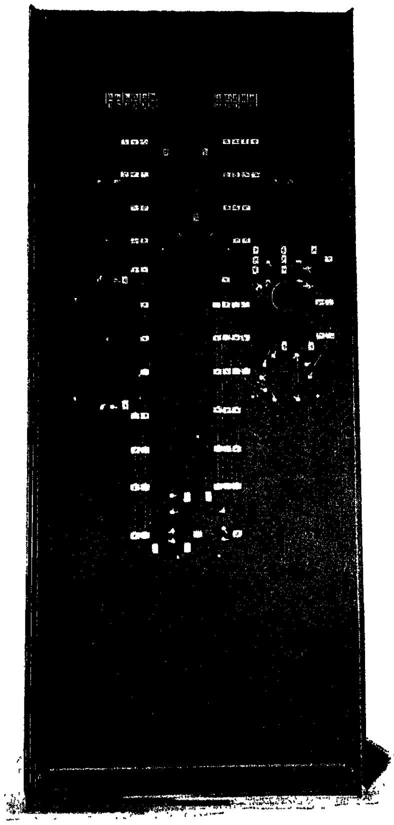


Fig. 11. Rear view of summation panel.

cification regarding oil temperature if conductors were carried down in the usual manner past the oil tanks to the cable boxes, on account of the induced current set up under these conditions in the sides of the oil tanks. For reducing these eddy currents to a minimum every switch has been provided with a special conductor system from which current is carried to the cable boxes through three vulcanised cables, one for each phase, which are held together in suitable racks. The arrangement is in accordance with fig. 15. Furthermore, the connections to the switches are made in such a way as to provide for easy and quick dismantling.

Instruments.

All the Instruments are of Englich Manufacture and suitably designed for use in the tropics.

Small Wiring.

All small wiring is carried out in 3 mm² specially insulated wire, supported in porcelain cleats in accordance with fig. 11. In each panel circuits are ended on terminalbars where connections can be simply and safely made. The arrangement is furthermore such that a test can be made if necessary on all the small wiring without interrupting work, and all danger of accidental short circuit between different terminals is entirely eliminated by placing protecting shields between each pair of connections.

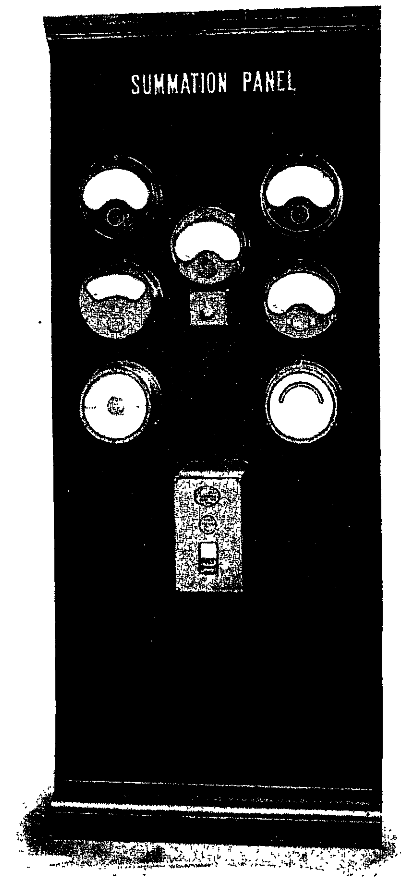


Fig. 12. Front view of summation panel.

Current and Potential Transformers.

The current transformers are compound filled with a special compound which has been found by experience to satisfy all requirements as regards co-efficient of expansion, melting point, and permanence of electrical characteristics in a tropical climate. The potential transformers are of the standard oil cooled type.

Relays.

The relays are of Asea's standard tropical design with ventilated covers.

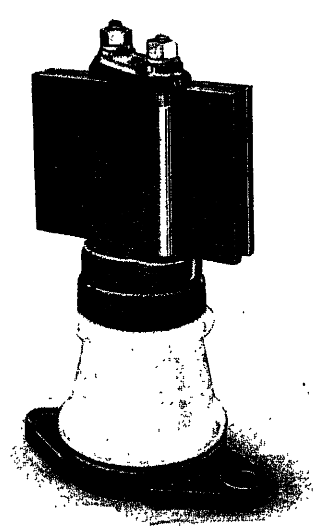


Fig. 13. Insulator with busbar clamp for 450 volt system.

All the switchgear was completely erected in Asea's workshops in Vesteras and tested before being despatched to its destination. All the various parts were carefully marked in the usual manner, which in a great degree simplified erection on site. Further, each switchboard was inspected and tested in the presence of the representative of the consulting engineer before leaving the shops. All current carrying parts were pressure tested, the 22 kV switchboard with 50 kV, the 6.6 kV switchboard with 16 kV, and the 450 volt system and all small wiring with 2 kV, all for 5 minutes, successfully showing that all

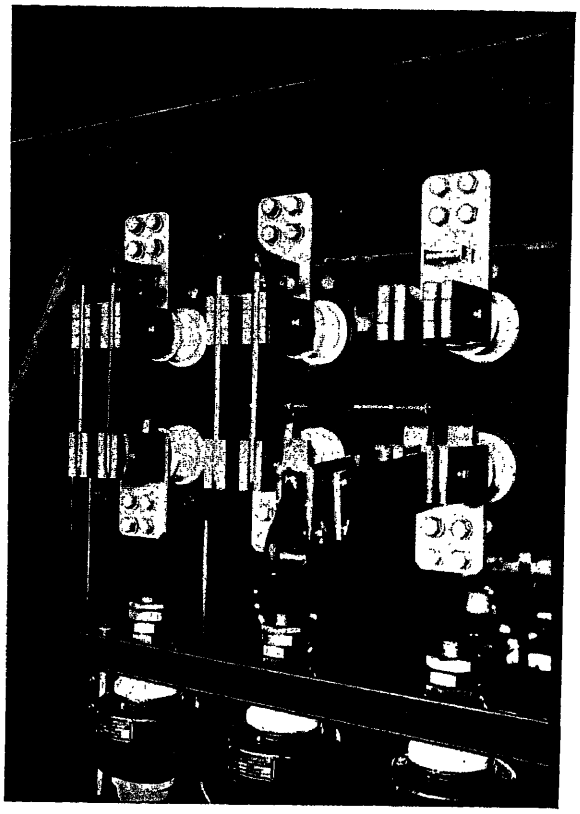
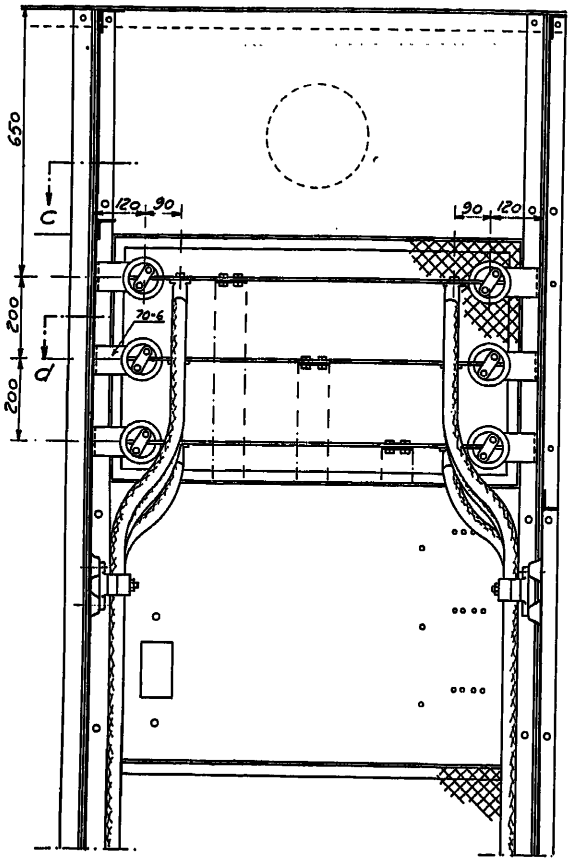


Fig. 14. Disconnecting links with locking devices, 450 volt, 1600 amp.



Section 6-

Fig. 15. Connection of cables in 450 volt cubicle.

details of the construction met the specified requirements in this respect.

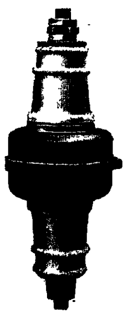


Fig. 16. Current transformer Type EC.

Each panel is provided with ornamental designation plates and each switch handle with an automatic device showing the position of the switch, which to a great degree simplifies the operation of the gear, which will be worked for the most part by unskilled personnel.

In order to protect the gear during its long journey, the packing was carried out with particular care. All instrument transformers, release coils, as well as instruments, and relays, were packed in oil impregnated fabric so that any damage by sea was out of the question.

The whole order was handled by Asea's representatives in London, which during the progress of the work maintained contact between the customer's agent and ourselves and this was done in a way which in a great degree simplified the work of the Head Office. The highly satisfactory result obtained is in no small degree due to the concise and painstaking work put in by the Consulting Engineer.

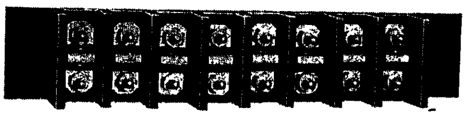


Fig. 17. Terminal bar for small wiring.

MODERN MOTOR INSTALLATION PRACTICE.

Anyone who has found interest and time to devote to Asea's price lists will have observed that of late years increasing space has been taken up by apparatus and machines of totally enclosed form, and that a general standardisation of the details runs through all these manufactures. These totally enclosed iron-clad constructions have been used increasingly year by year and their suitability for situations where the danger of fire is to be apprehended, or which are damp, for outdoor use, or mounting inside workshops is undeniable. It was in a very early stage of its activities that Asea constructed its first enclosed iron-clad apparatus, and as the original designs were greatly appreciated by many customers, work in this direction was continued and considerably increased as time went on. This development has been assisted in no small degree by the products which have been introduced by Swedish cable-makers during the same period.

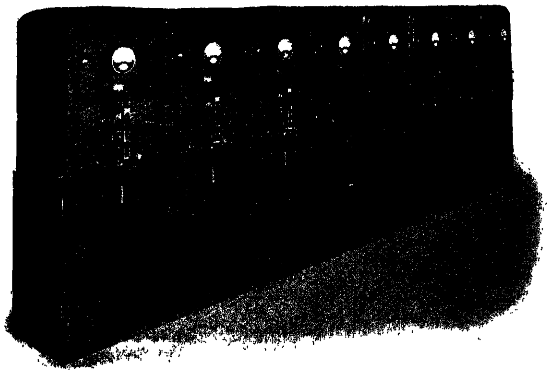


Fig. 1. Main distribution board made up of switch-cases type SBH.

This can be noticed by reading, with a little care, between the lines in the Asea lists. At the same time one can also see, that there is no haphazard provision of enclosures for apparatus, either to protect the apparatus itself against the surroundings, or to protect the surroundings against danger arising from the use of electricity, but, on the contrary, a definite principle of construction, which has gradually been brought to bear on the whole system of details which go to make up an installation. The intention at first was to obtain more durable and dependable apparatus and the enclosures were designed accordingly without any particular regard to the external conductors and cables. But is was soon found that the external connections stood in great need of improvement and this was effected by enclosing all wiring in conduit and tubing or by using wire-armoured and lead-covered cables. To complete this advance in installation work Asea added suitable connection fittings to suit the improved systems.

As mentioned above the enclosed installation system is described in Asea's lists and all the various details will also be found fully dealt with. On account of the arrangement of the lists, which is determined by various considerations, the enclosed and iron-clad constructions will not be found, however, collected together in one place, but must be sought in different sections of the lists. Accordingly, for the sake of greater clearness we have collected together such enclosed apparatus and machines which, when used in conjunction with one another go to make up a complete installation, although we shall here deal only with standard constructions for low voltage, *i. e.* up to 500 and 800 volts, and designed for installing in workshops

Fig. 2. Main distribution board built up from switch-cases type SBH and distribution boxes type GSH at the Swedish State Railway workshops at Orebro.

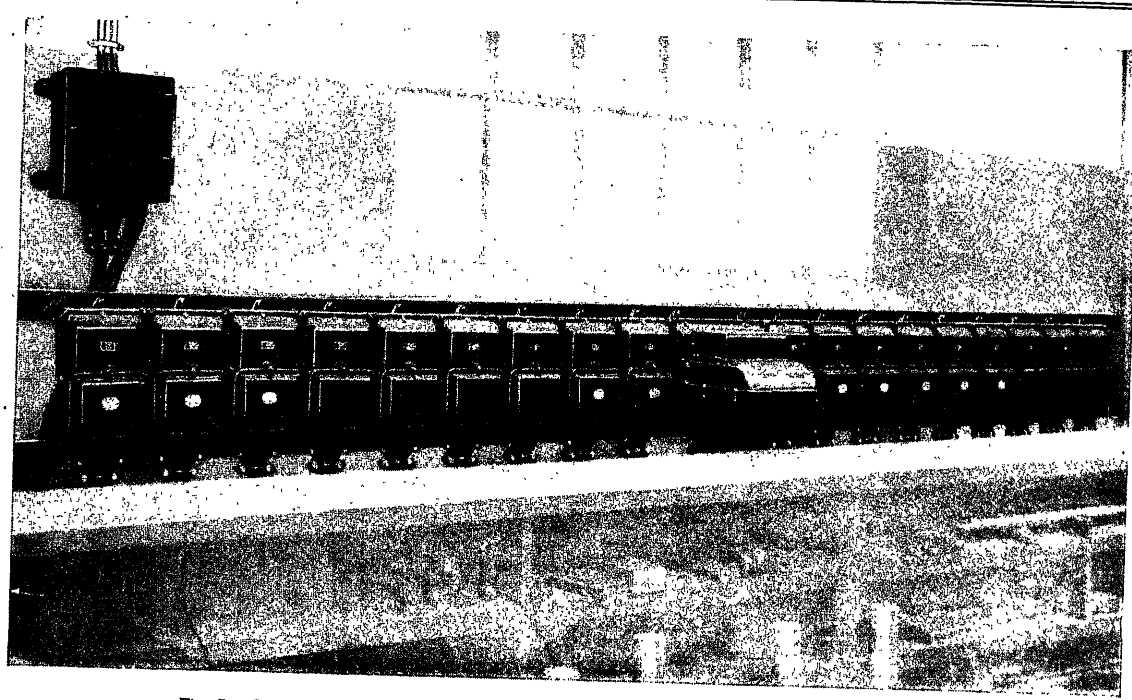


Fig. 3. Circuit distribution board type GS at the Swedish State Railway workshops at Orebro.

and those situations where fire risk must be considered, or damp localities.

In a power and lighting installation in a large mechanical workshop or large industrial plant, the power distribution for lighting, motors, and other current using apparatus is effected by a number of feeders which are collected together at a main distribution centre where over-load protection and switches are placed. In a large works these distributing boards are arranged in groups in the various shops and the feeders to them are in their turn brought to a main distribution board. In some cases the works possess their own generating station, and in this case the necessary switchboard with distributing feeders will be placed in this station; in other cases the works obtain their power through a feeder cable from some outside power station or transformer sub-station. In the last case the main distribution board need not be placed in a special room, but can be erected in any suitable place inside the factory, and may be composed of motor switch-cases of type SBH or instrument cases of type PFH, either erected together or as separate units.

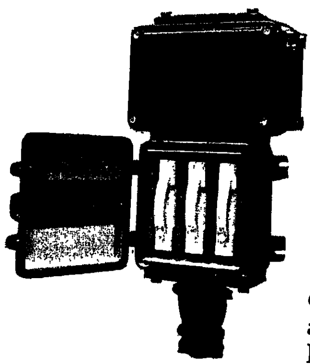


Fig. 4. Distribution box type GSH.

These motor or apparatus switch-cases contain oil-immersed circuit breakers and overload protection, the last in the form of fuses or overload relays for the oil switches, ammeters, voltmeters, and kWh meters, as well as other apparatus required in connection with the instruments and switchgear.

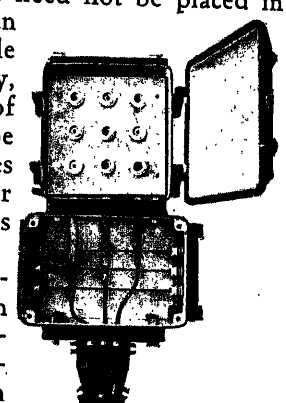


Fig. 6. Three-pole dividing box type GKS.

The SBH switchcases can be separately mounted or built into groups, and can be supported on the wall or arranged for floor mounting as shown in figs. 1 and 2. In these switch-cases can be placed oil switches of

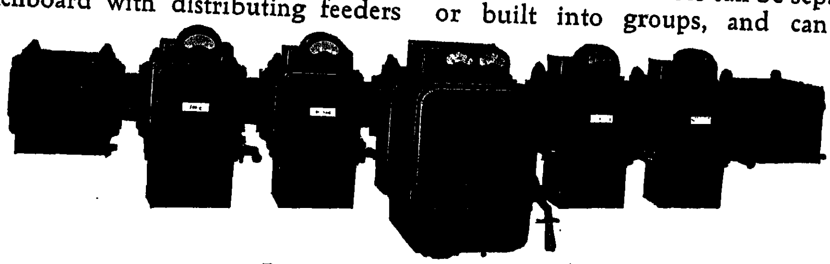


Fig. 5. Distribution board type GSB.

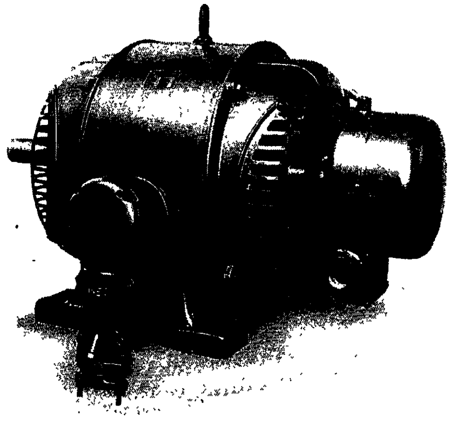


Fig. 7. Three-phase motor type MK.

type HL for a normal current up to 1,200 amps at 800 volts and for a breaking capacity of 13,500 kVA. These are more fully described in list E II.9. Switch-cases of type PFH are arranged for floor mounting and can be fitted with oil switches of either type HL or HO. Like the SBH switchcases they occupy a small amount of space and are designed to allow of easy access for inspection, and are provided with effective interlocking arrangements which protect them against mistakes in handling.

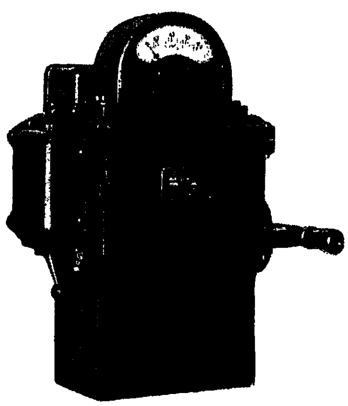


Fig. 8. Motor switch-case type SBK.

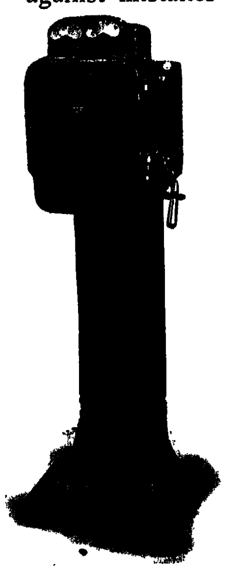


Fig. 9. Motor switch-case type SBO on pedestal.

From the main distribution board cables are run to ironclad distribution boards placed in suitable positions throughout the works, or if there are large and heavy motors, then direct to these.

Distribution boards of Asea's design are made in three main types; a smaller type GS for 25 and 60 ampere plug fuses respectively and 500 volts as a maximum, with busbars for 200 amperes; a larger type GSH for 60, 100, and 200 ampere replacement fuses and 800 volts as a maximum, and with busbars for a maximum normal current of 450 amperes; and a type known as GSB consisting of a busbar system for 450 amperes, 800 volts, which can be combined with Asea's standard motor switch-cases type SBO and SBK for 80, 130, and 200 amperes. Figs. 3, 4 and 5 show these distribution boards which are further described in list E III.13. A fourth type of distribution board consists of the dividing box type GKS, see fig. 6, which contains 25 and 60 ampere plug fuses for 2—4 outgoing 2 or 3 phase lines. The ironclad distributing boards can be mounted on the wall or erected upon a separate framework and the different types of distributors can be combined together through simple coupling pieces permitting a distributor to be made up to suit any desired equipment, up to the total current given above.

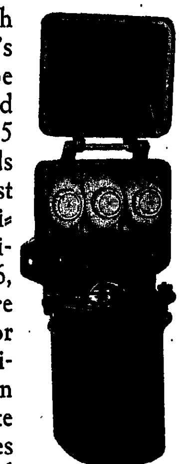


Fig. 10. Change-over switch type KKS.

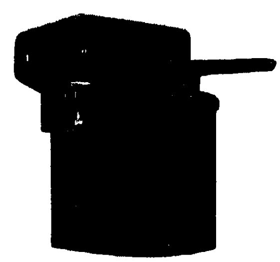


Fig. 11. Y/D change-over switch type KY.

Connection of apparatus, lamps, motors etc. to the distribution boards can be made by vulcanised cables run in steel tubing, or by armoured and lead covered cables of which the last-named may be recommended as being in general the best. As regards lighting installations we must limit ourselves to mentioning the existence of ironclad plugs and sockets, switches etc., of Swedish make which are particularly suitable for this service. With reference to power installations *i. e.* motors, and other starting apparatus, we refer the reader to list E XVI.1A in which Asea's new series of motors, with their enclosures, and terminal arrangements, are fully described. These motors are provided with dustproof covers for the sliprings, but the machines can be further enclosed, and their windings further protected, by placing different covers on the endshields. By changing these covers it is possible to obtain a drip-proof motor (Form E), an enclosure for connecting to ventilating ducts (Form P), and a completely enclosed motor without ventilation (Form Q). The terminal boxes are arranged to take tubing or cable as regards the stator, and they are normally arranged for screwed tubing on the

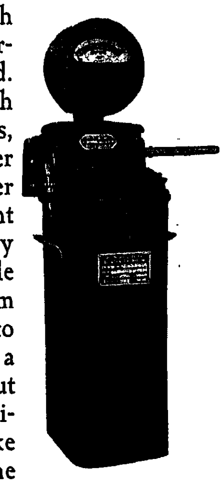


Fig. 12. Oil immersed starter with primary switch PTCP.

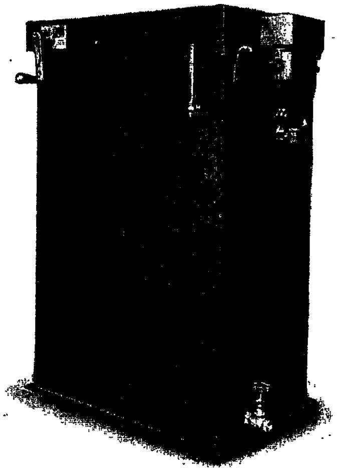


Fig. 13. Oil immersed starter type PTK.

rotor side, while this last connection can be completed by adding a cable-box type LP, which is described below. Fig. 7 shows a standard three-phase motor with a cable box for the stator terminals, and with the rotor terminal box screwed for tubing.

For starting these motors several different kinds of apparatus can be used. Squirrel-cage motors can be started by changeover switches of type SBK, SBD, KKS, or KY (KYS) or with an auto-starter type ATS. The two first named, and the auto-starter for 80 amperes and above, can be embodied in the distribution boards themselves, or placed near the motor, on the wall, or upon a pedestal, but K type switches can only be erected separate from the distribution board. The starting apparatus referred to here is described in list E II. 8, and is illustrated in figs. 8—11. For starting slipring three-phase motors one can either use the oil-cooled starter type PTC and PTK, for small and large motors respectively, if primary switches of type SBO are used on the distributing board (which is in this case assembled as type GSB); or starter type PTCP containing oil-cooled starter and primary switch can be employed if distribution boards of type GS and GSH are used; and lastly the starter switch-case type PSC, model I and II, containing primary switch, overload protection, and oil-cooled starter can be employed in either of the cases referred to above, and this may certainly be considered necessary if more than one motor is run from the same fuses on the distribution board. Oil immersed starter type PTC, PTCP and PTK will be found in list E II. 3 A and the starter switch-case PSC in list E II. 10. They are illustrated here in figs. 12—15. If portable motors or other apparatus are used they can be coupled up to the installation by plug contacts of type KP and KPA, see list E III. 12 and figs. 16 and 17, and if for these or other purposes separate fuses and switches are required, then the iron-clad types KS and KA respectively are suitable, which are constructed for 25 and 60 amperes. See list E III. 12 A and figs. 18—20.

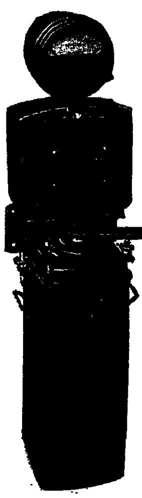


Fig. 14. Starting switch-case type PSC, model I.

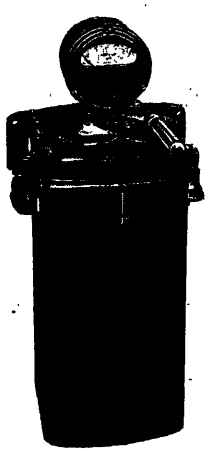


Fig. 15. Starting switch-case type PSC, model II.

Fig. 16. Three-pole plug-box type KP.

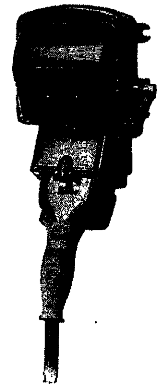


Fig. 17. Three-pole plug-box with switch type KPA.

Above we have referred exclusively to an installation in a large factory. It will be clear however that smaller installations can be carried out with ironclad apparatus as described, and from the large plant which requires a main distribution board and a number of smaller circuit distribution boards, down to the very small installation with only a few circuits it will be found that any size can be equipped throughout on the same system. The chief advantages have been touched on above and include practically unlimited life even under unfavourable installation coditions, perfect protection for the electric conductors and apparatus against all mechanical and chemical damage, as well as protection against shock to men and animals, and, from the point of view of fire risk, against all danger due to the use of electricity. It is inevitable that an installation of this nature should be somewhat more expensive than one carried out with ordinary installation material, unless the small amount of space required by the distribution boards is taken into account, but on the other

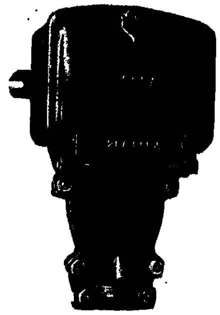


Fig. 18. Three-pole fuse-box type KS with divided cable end-box.

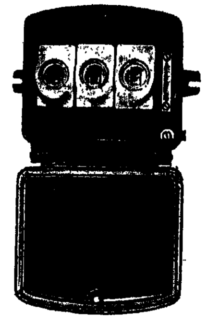


Fig. 19. Three-pole fuse box type KS.

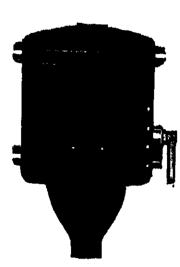


Fig. 20. Three-pole switch type KA with undivided cable-box.

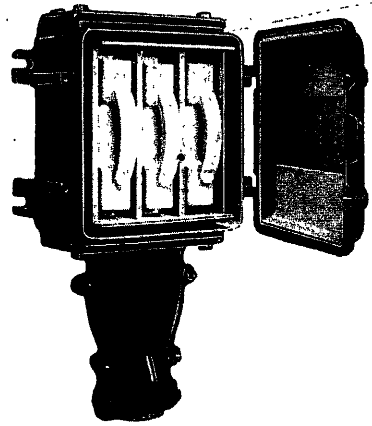


Fig. 21. Three-pole fuse-box type KSH.

Fig. 22. Divided end-box type LR.

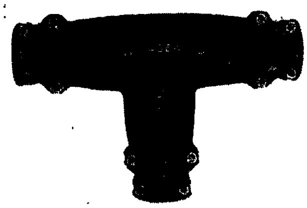


Fig. 23. T-box type LT.

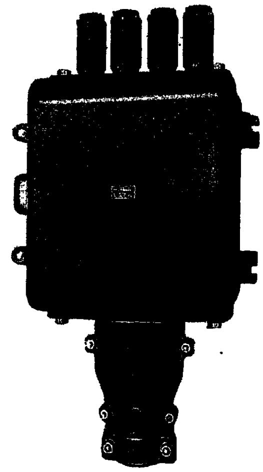


Fig. 24. Cable end-box type LP combined with dividing box type GKS.

hand it has been clearly proved by experience and theoretical considerations that the increased amount laid out on the better installation is very well utilised.

By way of a conclusion to the above we may draw attention to the complete series of cable boxes for indoor installation and placing direct in the ground. This series consists partly of end boxes and partly of dividing and branch boxes for cables to 400 mm² and voltages up to 11,000 volts. They are further described in list E IV. 14 and are illustrated in figs. 22 and 23. Dividing and branch boxes are of great use throughout a cable network, and for ending cables inside houses etc., the iron-clad fuse box type KS can be used as a service box.

Apparatus of this kind is made 1, 2 and 3-pole with neutral lead, for 25 and 60 amperes, and can be supplied with divided or undivided cable boxes for incoming cables. Outgoing lines are usually arranged for steel conduit, but can also be furnished with cable boxes of type LP. For higher currents the 3-pole ironclad fuse-box type KSH is suitable, and this is made in three sizes for 60, 100 and 200 amperes, with replacement fuses and fireproof shields fig. 21. They can be provided with cable boxes for incoming and outgoing lines but are also suitable for conduit fittings. A small detail of special interest is also the cable box type LP which is used almost universally on smaller apparatus for currents up to 100 amperes. This box is divided and can be mounted in all positions to suit cable entering from above, from below, or from one side. By using a small collar they can be fitted to holes threaded for screwed tubing, 28.3 mm diameter and above, and can consequently be used on all Asea's smaller iron-clad apparatus. This method of fitting also permits LP cable boxes to be used on old installations where Asea's apparatus has been fitted. They are shown applied in different positions in figs. 24—27.

Our review of modern installation practice has been fairly lengthy, but at the same time space has of necessity been curtailed as far as possible. We have accordingly only given a short description of the system as a whole, and referred to Asea's motor and apparatus lists for fuller descriptions of the various details employed. It is hoped, that this sketch will be of use as a guide to those who are in any way concerned with power installations.

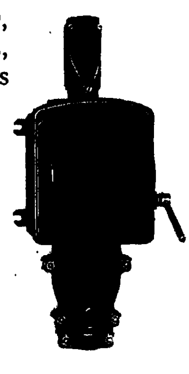


Fig. 25. Cable end-box type LP fitted to switch type KA.

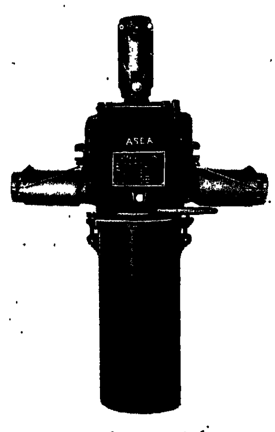


Fig. 26. Starter switch-case type PSC with cable-boxes type LP.

Fig. 27. Plug-box type KPA with cable-box type LP.

Vesteras 1925, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

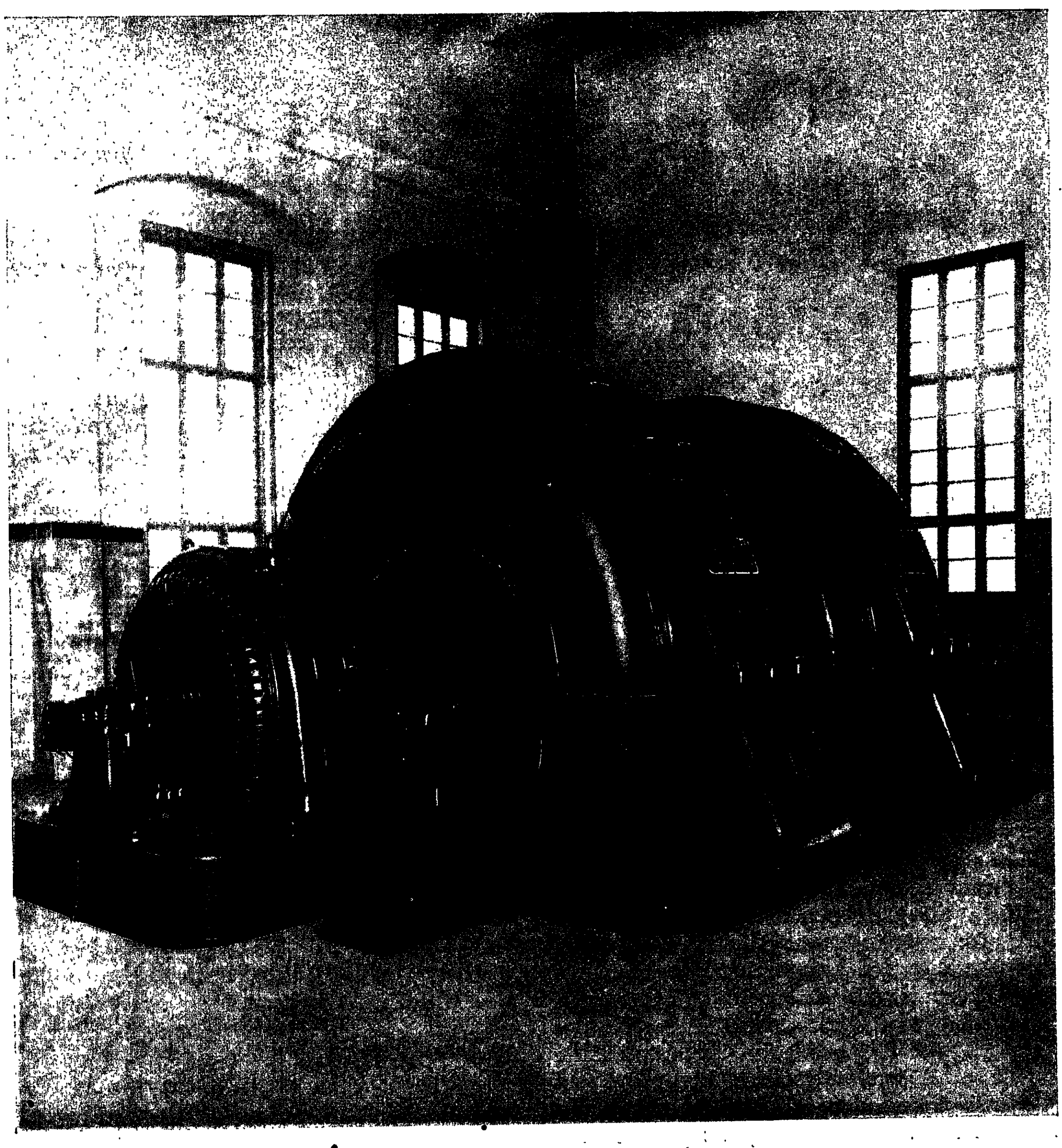
ALLMÄNNA SVENSKA
ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

VOL. II
1925

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesterås, Sweden.
Permission is given to reprint articles or extracts from this journal,
on condition that the name — Asea-Journal — is clearly stated.

FEBRUARY
No. 2



5,000 kVA frequency-changer 50/25 cycles, 375 r.p.m., 10,000 volts, consisting of two synchronous machines with starting motor for use on either frequency.

ASEA SYNCHRONOUS MOTORS.

The struggle after economy, which has been taking place for many years now, in all branches of industrial work has manifested itself, in the domain of electrical power distribution, by the increased attention given to the power factor in alternating current systems. The considerable saving which can be effected in various directions by an improvement in power factor, so small as to appear almost negligable, has led not only to the consideration of improving the power factor on systems, by those themselves reponsible for the distribution schemes, but also

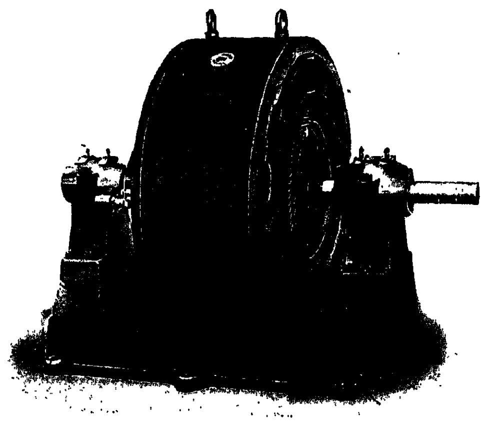


Fig. 1. Old synchronous machine with revolving armature.

to the introduction of charges for power which make it an advantage to the actual consumer to improve the power factor on his own installation, and consequently improve the power factor on the whole net-work. Among the different means which are available for this purpose, the synchronous motor can be looked upon as one of the oldest and most important.

Although the synchronous motor is as old as the synchronous generator, since practically any synchronous machine can be used equally well either as a motor or as a generator, it has not been used to anything like the same extent on account of the popularity of the induction motor, and this applies not only to Sweden but to most places except perhaps North America, where conditions are quite different.

Synchronous motors are made in general of two kinds, the usual synchronous motor (with salient pole rotor) is practically the same as an ordinary synchronous generator, while the autosynchronous motor in its construction resembles an induction motor, although like the first, it is supplied with DC excitation, from an exciter or some other external source. In the present article it is proposed only to deal with the first mentioned type. During the years prior to the war many ordinary synchronous motors were installed in Sweden, but their number scarcely represented 1 % of the total number of AC motors. This result has been contributed to by the success which has attended the introduction of the autosynchronous motor. During the last few years also, the conditions have not been altered in any great degree, although, at the same time, there is a marked tendency to displace the autosynchronous motor with the synchronous motor where the conditions are found suitable.

In spite of the above, Asea has had the opportunity of building large numbers of synchronous motors both for Sweden and abroad. These synchronous motors have now, as in earlier times, the same dimensions and general particulars as synchronous generators of the same size and only depart from these in small constructional details. The first synchronous motors built by Asea were, like the generators, constructed with stationary fields and revolving armatures. When the generator construction was gradually altered, so that the armature became fixed and the magnet field was made rotating, the motors also were built in the same way. The general appearance was the same for both types of machine as the same patterns were used at all times. At the present time synchronous motors are built generally of two types; those in the smaller sizes up to a maximum of 750 kVA at speeds from 250 to 1,500 r.p.m. at 50 cycles, all of standard open type and provided with end shield bearings; and larger machines up to a maximum of 7,500 kVA at speeds from 94 to 750 r.p.m. at 50 cycles, which are also, in general, of open type but furnished with pedestal bearings. The machines can be arranged in many different ways, having regard to the service on which they are to be used.

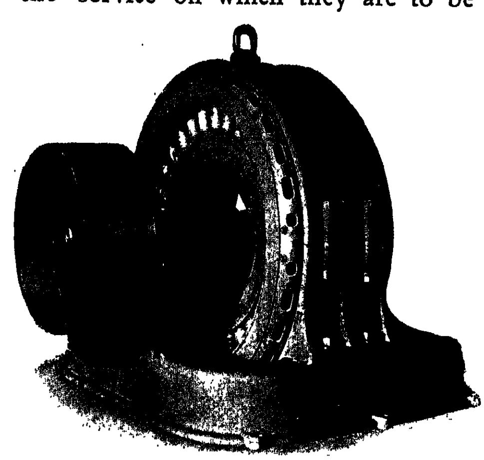


Fig. 2. Old synchronous machine with revolving field.

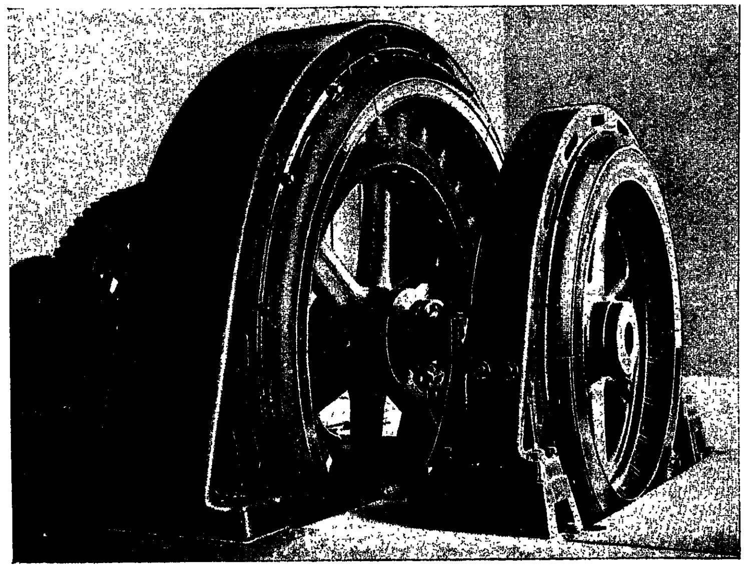


Fig. 3. 1,000 h.p. synchronous motor with starting motor, built in 1904.

Asea synchronous motors are always furnished with frames of cast iron in which a core built up of paper insulated sheet iron stampings is firmly held between press-flanges. The stator winding is carried out in slots which are in general semi-closed and for low voltages the bar winding is adopted, while for the higher voltages coil winding is used and, in threephase machines, is usually divided into two planes. Only the best insulating material is used and for pressures above 2,000 volts the winding is always insulated from the iron by seamless micanite tubes.

The rotating magnet field is, for the small machines, with end shield bearings, usually of cast steel with the poles and magnet ring all in one piece. The pedestal bearing machines have rotors with various constructions, for the smaller types cast in steel in one piece, and for larger types with pole cores of wrought iron, or cast steel, fixed to a magnet wheel of cast iron or steel. The field winding is in general, for the small types, carried out

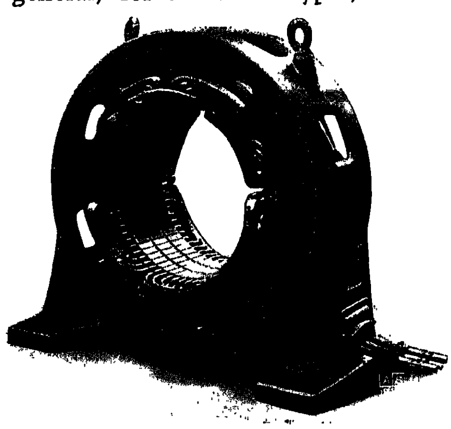


Fig. 4. Fully wound stator for a small modern synchronous motor.

with impregnated cotton covered wire of circular section, whilst the larger machines are provided with coils of copper strip wound on edge and insulated between turns with paper and shellac varnish. The field coils are held on the pole cores by massive pole shoes, which for small machines are of cast iron firmly held on with screws and for large machines are of cast steel.

Although for synchronous motors designed to run at no-load the mechanical details could very well be made much lighter than for generators or motors which are constructed for a large mechanical output, the synchronous motors supplied by Asea always have the same dimensions as the corresponding generator types. The shafts accordingly are of the same diameter, and are carried in bearings of standard oil ring pattern, which, in the case of large machines, are sometimes modified by the provision of an arrangement for forced lubrication during starting, in order to make starting easier.

The sliprings, brushes and brush-holders are amply dimensioned and are similar to the types used on corresponding generators. The stator winding in the case of large motors is in general brought out to the same number of terminals and arranged in the same way as for corresponding generators, the smaller motors for low voltages usually have their starting apparatus mounted direct upon their frames, and the terminals and arrangement of the winding accordingly varies somewhat from standard generator practice.

A synchronous motor is arranged in general for excitation from a DC supply produced at the machine itself, preferably from a direct connected exciter. In Asea synchronous motors this exciter has its armature mounted on an extension of the motor shaft, so that no additional bearings are required, and the field magnet of the exciter is either supported on a bracket on the end

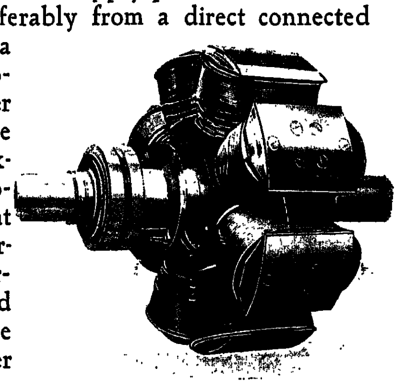


Fig. 5. Wound rotor for a small modern synchronous motor.

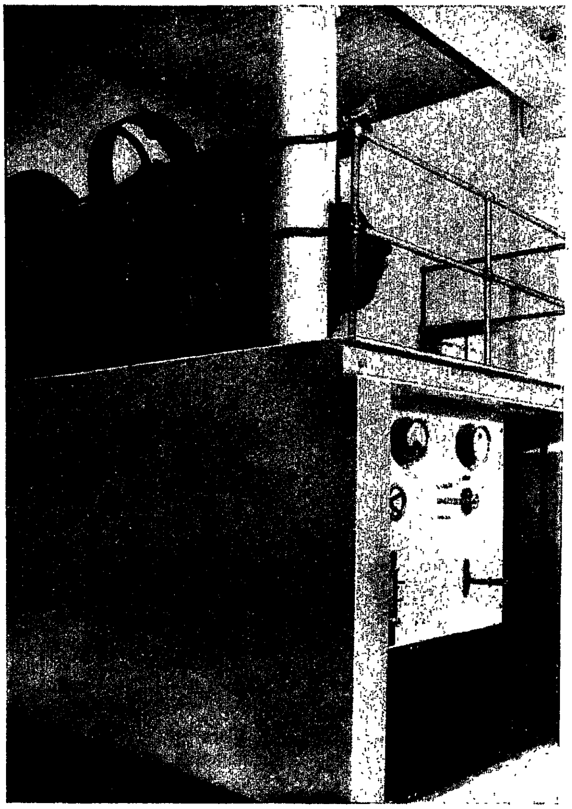


Fig. 6. 540 kVA self-starting synchronous motor with chain-driven transmission shaft.

shield or upon a special pedestal on the bed-plate or on the sole-plate which carries the outer machine bearing.

Like other motors those of the synchronous type require certain auxiliary apparatus for starting. The smaller types are made self starting and have a starting change over switch either carried direct on the machine or arranged for separate mounting, while the larger types have a separate starting change-over switch, if one is used, or, in other cases, an auto-starter which is also provided for the smaller types where the working voltage is high. Synchronous machines can also be run up to speed by a special starting motor which is usually an ordinary induction motor wound for the next higher speed to that of the main motor. When the synchronous motor has been started, the starting motor can be allowed to run disconnected from the supply, or alternatively a coupling can be provided on the shaft so that the machine can be entirely disconnected. It has been mentioned earlier how much the use of the ordinary synchronous motor has been retarded by the induction motor and autosynchronous motor. This has chiefly been due to the bad starting characteristics which are obtained. An autosynchronous or induction motor can, with the help of simple arrangements, be started direct from the supply from which it will be run and against full load without any particular difficulty. This could not be done with the earlier synchronous motors. Not only was it out of the question to start the machine against any load, but the actual starting and connection to the power supply was a particularly difficult operation demanding both skill and practice, the difficulties being greater the less complete the equipment of instruments and apparatus.

At the present time this drawback has been considerably reduced. For one thing the modern synchronous motors built by Asea can be started against load, although not exceeding more than a small percentage of the full load value for ordinary machines, whilst at the same time the necessary apparatus for synchronising has been entirely obviated in cases where motors are made self starting and connection to the supply has been simplified in a corresponding degree. In cases where synchronising is still necessary, the arrangements provided are practically automatic, and so perfect that starting up a synchronous motor has become child's play in comparison with the troublesome and time wasting operations which formally had to be carried out.

Asea's self starting synchronous motors are in general arranged either for starting by the so called series-parallel system or with reduced

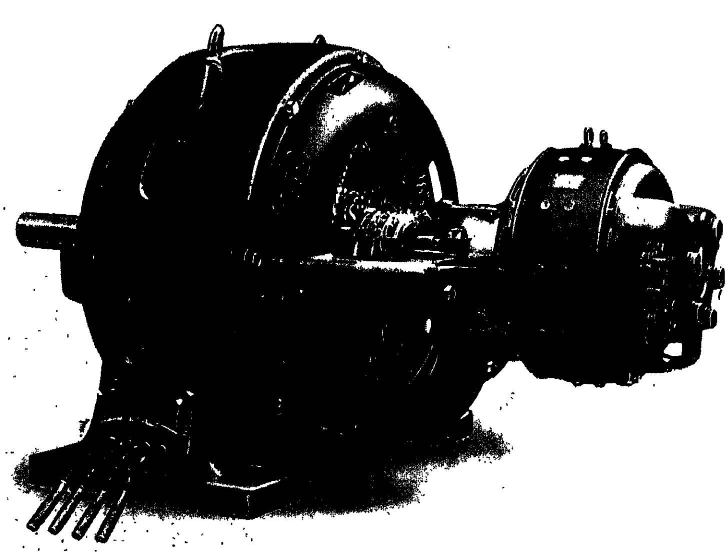


Fig. 7. Self-starting synchronous condenser with direct connected exciter.

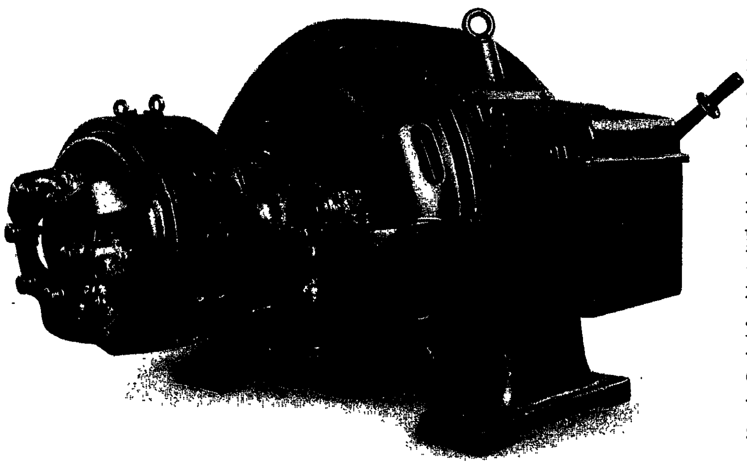


Fig. 8. Modern self-starting small synchronous motor with exciter and self-contained starting apparatus.

voltage. The former system derives its name from the fact that the stator winding of the motor is carried out in two parallel circuits per phase, which are connected in series at starting and, after synchronism is reached, are connected in parallel for running. The second system works with the help of an auto-transformer starter by which the motor is connected to a suitably reduced voltage for starting and changed over to full voltage when it has reached full speed. The series-parallel system can be compared with the ordinary Y/D starting of squirrel cage motors and this can in fact also be used for making synchronous motors self starting, the effect being practically only to reduce the voltage at the motor to about half the supply voltage by doubling the normal voltage of the machine. As for practical reasons it is not easy to arrange a motor with series parallel connection for more than one arrangement of connections, the starting characteristics of the motor are fixed when the machine is designed and cannot be altered afterwards to any considerable degree. The use of an auto-starter permits greater flexibility of starting characteristics and also allows these to be adjusted when the machine is finished if this should be found necessary. This greater flexibility makes the equipment rather more expensive than a machine furnished on the series parallel starting system.

With both methods of starting the motor behaves like an ordinary induction motor, starting by itself, and accelerating up to full speed, after which it is switched on to full voltage and the fields excited. The machine then runs in synchronism and is ready to take up full load. All the apparatus necessary for starting is arranged and connected up so that the whole starting operation can be done with the help of a couple of handles, and the machine started by any inexperienced person. When using the series parallel starting system the motor can be run up against a load corresponding to about 15 % of the normal, and then takes about normal full load current at starting, (if a heavier current can be allowed the starting torque may be increased), and when switching over to the normal full voltage there is a current rush of about the same amount. The power factor at start is about 0.3. When using an auto-starter about the same power factor is obtained, but the starting current etc. can, as stated above, be adjusted so that this starting method should be used when the series-parallel starting system does not permit of a sufficiently high starting torque, or else gives rise to a starting current which is too high. The auto-starter must further be used in all cases where the supply voltage is so high that series-parallel connection is unsuitable from the point of view of the design of the motor.

Starting with the help of a special starting motor is, of course, one of the oldest and best known methods, and in starting in this way the first operation depends entirely on what kind of starting motor is employed, and the characteristics of the start are derived entirely from this machine. The second operation, when the machine is up to speed, involves the ordinary procedure adopted in paralleling two gene-

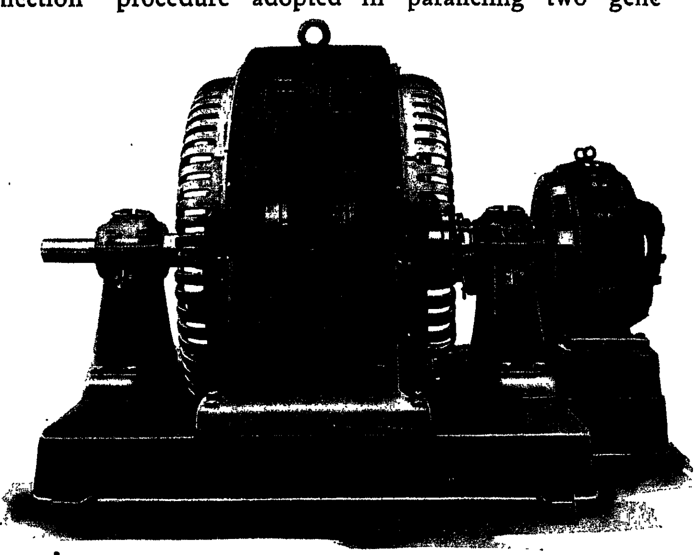


Fig. 9. 1,500 kVA self-starting synchronous motor with direct-connected exciter.

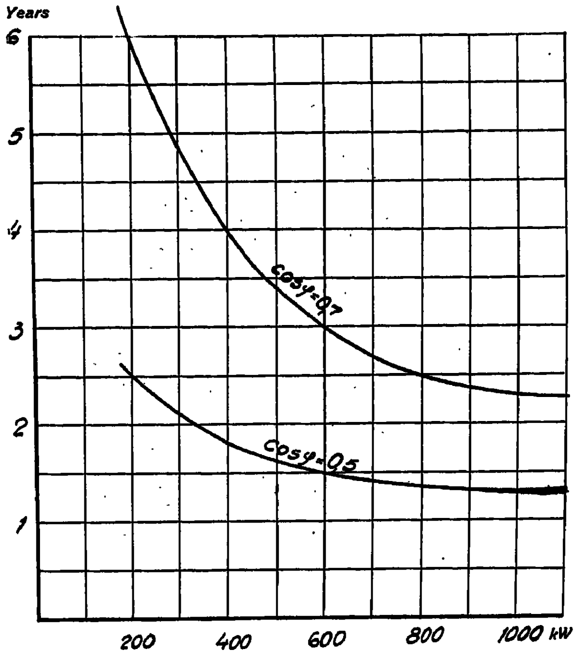


Fig. 10. Number of years required for amortisation of a synchronous motor designed for raising the power factor from the values given on the curves to 0.8. Present day machine prices are assumed and a price for reactive current of 0.15 d per rkWh, further that the machine is used 1,000 hours per year and with interest at 6 %.

rators. Other methods also exist for starting synchronous motors but may be passed over here.

After the synchronous motor has been connected to the supply it continues to run, as long as the supply frequency remains constant, at a constant speed which is independent of the load. If the motor is overloaded its speed accordingly does not drop but is maintained at the normal value until an overload of such magnitude arises that the motor falls out of step and immediately pulls up. This effect is obtained at an overload the magnitude of which depends on the design of the motor. Asea motors, other then those which are built exclusively for use as synchronous condensers, can be momentarily overloaded from 100—150 % without falling out of step.

At the commencement the use of the synchronous motor for improving power factor was referred to. This depends on the ability of the synchronous motor to give, by varying the magnetisation, such a relation of its armature current to the supply voltage that it is possible to obtain any required phase displacement relative to the supply, positive or negative, depending on the size of the machine. When running over-excited the machine acts as a capacity load, and when under-excited, as an inductive load. As in general the load on any power network is inductive, *i. e.* has a positive phase displacement, the synchronous motor is practically always required to run over-exited, *i. e.* with negative phase displacement, and thus neutralise the inductive load and so give a value to the overall power factor wich permits economical working.

There are two alternatives to choose from. One may either instal an electrically loaded but mechanically unloaded synchronous motor, generally known as a synchronous condenser (also called phase advancer*), or use can be made of a synchronous motor which is both electrically and mechanically loaded. In the former case no alteration whatever is made in the general equipment of the plant, but a synchronous condenser is simply erected at some suitable place on the network to supply the necessary reactive energy to obtain the required value of the power factor. In the latter case it is possible, for example, to exchange an already existing induction motor for a synchronous motor so designed that it can give the same mechanical output as the induction motor, and at the same time supply the necessary reactive energy. Of these two alternatives the second is in general the best, having regard only to the size of the synchronous machine required, as the properties of the synchronous motor are in this case better utilised. For the same outlay as the provision of a synchronous condenser would necessitate, it is possible to instal a motor which will give the same improvement in the overall power factor of the network, and at the same time supply a certain amount of mechanical power. Which method is the most economical must be investigated in each particular case, and this can be done as far as the synchronous machine is concerned by making a few simple calculations, examples of which are given in our price lists covering these machines. As there are so many possibilities to be considered, it is very difficult to put forward any rule which is capable of general application.

At this point we come to the question of the advantages obtained by the installation of a synchronous motor. The first thing to be considered from the point of view of the purchaser is the reduction to be effected in the power bill.

In fig. 10 is illustrated an example showing how many years are required by a synchronous condenser to pay for itself, with the price of electrical machinery ruling at the present time, and with a charge for reactive power of 0.15 pence per rkWh**). The improvement is estimated to be effected during a running time of 1,000 hours per year and the rate of interest is taken as 6 %. The output of the motor is so

*) The name phase advancer is more usually applied to a secondary machine running in conjunction with an induction motor for improving the overall power factor.
**) Rekilowatt hour or kWh of reactive energy.

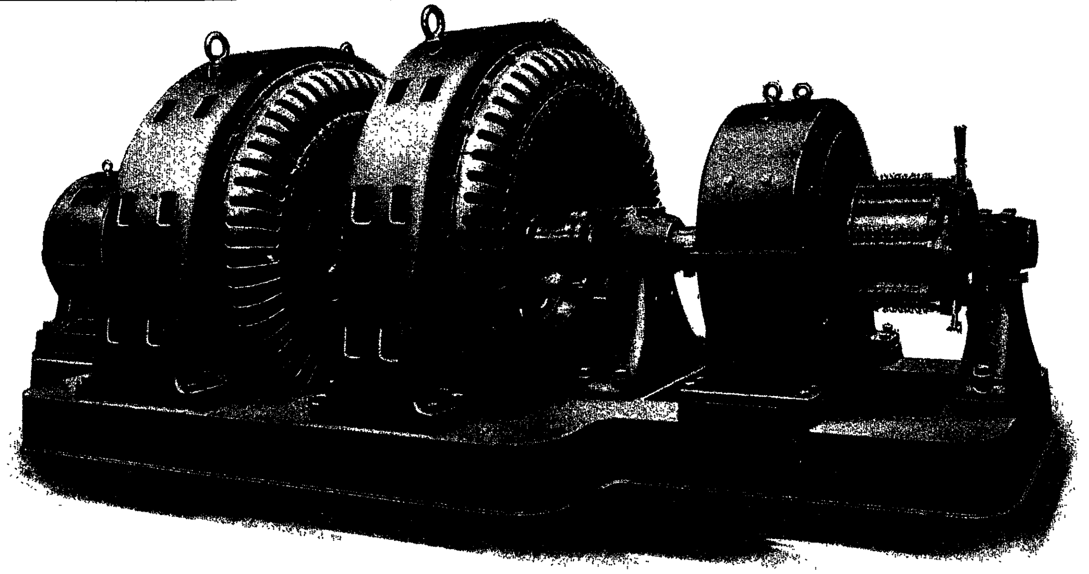


Fig. 11. Frequency-changer consisting of a starting motor, synchronous motor, synchronous generator, and DC generator.

calculated that the overall power factor is raised to 0.8. Thus the lower curve in the figure shows that for a 500 kW installation with an original power factor of 0.5 a synchronous condenser which raises the power factor to 0.8 pays for itself within 1.6 years of its installation. Further comment is unnecessary. If the motor is in use for a greater or less time than 1,000 hours in each year, the time given will be altered in the same proportion. The above, however, does not represent the total gain. There is a long list of possible improvements throughout an electrical installation commencing with a better utilisation of the primary power at command, no matter in what form it is supplied to the generator for conversion into electrical energy, and ending at the premises of the consumer where, for example, the light is more steady etc., all of which are obtained by the help of the synchronous motor. The advantages obtained by the installation of a synchronous motor or condenser are accordingly not only derived by those who are for some reason or other obliged to purchase the machine. AC installations which have a power factor higher than 0.8 are certainly not to be reckoned in large numbers, and for all those possessing lower values the question of the purchase of a synchronous motor is so important that it should be considered whenever extensions are under discussion.

As we mentioned above, the synchronous motor is most usefully employed if it can at the same time supply both active and reactive power. As the starting of synchronous motors has now been so simplified and improved, these machines can be considered in many more cases they could previously. The smaller and medium sized motors can accordingly be used with advantage in all cases where starting can be done against a small proportion of full load torque, as for example in motor generator sets, and for driving all machines which can be started with the help of fast and loose pulleys, friction clutches, or magnetic couplings, so that the load can be taken up after the machine is running in synchronism. The motor can always be made self-starting by one of the methods refferred to without giving rise to any difficulties whatever, so that the condition which was often formerly applied to synchronous motors, "that they should not require to be started frequently", no longer applies.

For larger synchronous motors, when machines for one or two thousand kVA and above are in question, the conditions are somewhat different. If the power supply system is so large that the considerable amount of power, at low power factor, required for starting, can be obtained without causing other difficulties, the self-starting method can be used here also. In other cases starting must be effected by a special starting motor before the machine is loaded. Here the conditions are in principle the same as they were formerly and no great increase in use can be expected as it may be for small and medium-sized motors.

This article shows, however, that the construction and characteristics of synchronous motors have been very considerably improved in many respects, and that these machines are now of very considerable service in industrial work. In all cases where a choice is possible between different kinds of motors, it is accordingly desirable to determine in the first place if the use of a synchronous motor is permissable.

HEATING OF OIL INSULATED TRANSFORMERS.

In air insulated transformers the transference of the heat caused by losses to the cooling medium, the air, takes place practically direct and the amounts of heat generated in the core and in the windings respectively do not greatly influence one another. The load that can be carried by an air insulated transformer — especially as regards a fluctuating load — is accordingly chiefly dependent on the heat capacity of the copper and insulation in the windings and on the cooling properties of the air. The temperature in the windings accordingly follows variations in the load relatively quickly and the overload capacity of such transformers is very small.

In an oil insulated transformer these characteristics are quite different on account of the fact that the heat generated is transferred to the cooling medium (air or cooling water) through the oil. The temperature rise in the oil is dependent on the total losses in the transformer, and thus the total temperature rises in the windings and in the core above the temperature of the cooling medium exercise an effect upon each other. The load capacity of an oil insulated transformer — especially with regard to varying loads — depends accordingly upon how the losses in the core and windings compare with one another and upon how the temperature rise in the oil compares with the temperature rise in the windings above the mean temperature of the oil. It is well known that the overload capacity of an oil insulated transformer is considerably greater than that of an air insulated transformer on account of the relatively much greater heat capacity of the oil, and this also depends, as will be shown in the following, upon the relations mentioned above between the losses in the core and windings and between the different temperature rises. The determination of the overload capacity of an oil insulated transformer entirely from the temperature rise observed in the oil, which is done in many cases, is accordingly dangerous to the transformer, and we intend to show how unsatisfactory such a method can be.

In order to judge the temperature conditions in a transformer subjected to variable load, we determine the temperature relations in, for example, a water-cooled transformer with continuous full load and constant temperature of the cooling medium and derive from this the characteristics for other loads. We refer to figure 1 which shows a section of the active parts of a water-cooled core type transformer and indicates the chief directions along which the oil circulates when the transformer is loaded. The heat generated in the core and windings warms up the surrounding oil and is slowly conducted away by the cooling coils in the upper part of the transformer, where the oil comes in contact with the cooling tubes, and gives up its heat to the cooling water, is cooled, and sinks down the sides to the bottom of the tank. With continuous full load the maximum and mean temperature rise of the cooling medium above the incoming temperature, on the assumption that a constant quantity of the cooling medium passes per unit time, is proportional to the transformer's total losses. This is also the case with the maximum and mean temperature rise of the oil above the mean temperature of the cooling medium.

In order that the heat generated in the core and windings can be transferred to the oil, these parts must be at a certain temperature above that of the surrounding oil. The dimensions of these parts being considerably smaller in the radial than in the axial direction, the transfer of heat from the respective parts to the oil takes place chiefly radially, and it follows that, for all practical purposes, the same mean temperature difference exists, between the oil and the surface of the heat radiating parts, in the lower, as well as in the upper sections, of these parts. In these active parts themselves, there exists a certain definite temperature difference between the surface and the inner sections depending on the heat conductivity of the iron, the copper, and the insulating material in use. These two temperature rises above the surrounding oil can be taken to be proportional to the total losses in the respective parts, that is to say, proportional to the iron loss in the core and to the copper loss in the windings.

Assuming the line voltage constant, the iron losses are practically constant, in spite of varying load, and accordingly the temperature of the iron core above that of the surrounding oil remains practically constant. The highest temperature reached by the core with variable load and with different temperatures of the incoming cooling medium, is thus only dependent upon the mean temperature of the surrounding oil. If the transformer is run with such a load that the maximum temperature of the oil does not exceed the highest allowable with the highest allowable temperature of the incoming cooling medium, then if the temperature of the incoming cooling medium is actually lower than the highest which can be permitted, the mean temperature of the oil, and accordingly of the maximum temperature of the core is somewhat lower than that which would be obtained with constant normal full load and highest permissible tempe-

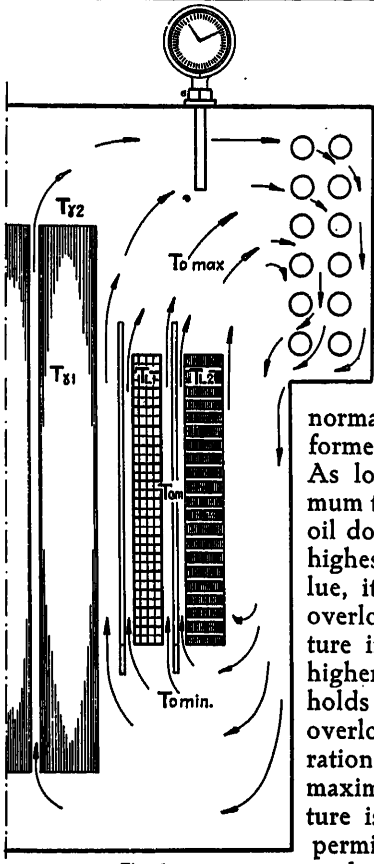


Fig. 1.

rature of the incoming cooling medium. As, however, the temperature rise of the oil above that of the incoming cooling medium must then be greater than normal, the transformer losses are also greater than normal, *i. e.* the transformer is overloaded. As long as the maximum temperature of the oil does not exceed the highest permissible value, it follows that, on overload, the temperature in the core is not higher than normal. This holds good also for overloads of short duration, as long as the maximum oil temperature is kept within the permissible value. In studying the overload capacity of a transformer we must accordingly disregard the temperature effects in the core.

In the windings the temperature effects are altogether different. As previously mentioned, the temperature above that of the surrounding oil is in this case directly proportional to the loss in the windings, and accordingly the mean temperature increase of the windings (measured by resistance) above the mean temperature of the oil, as well as the maximum temperature increase in the windings (the "hot spot" temperature) is proportional to the square of the load. The mean temperature of the windings is accordingly compounded of one temperature increase proportional to the square of the load, one proportional to the total losses of the transformer, and one temperature depending on the incoming temperature of the cooling medium. The transformer is normally calculated so that the mean temperature in the windings with continuous full load and with the highest anticipated temperature of the incoming cooling medium does not exceed the highest temperature permissible for the windings. If now the temperature of the cooling medium does not go up to the predetermined maximum value, it is obvious that the transformer can to a certain extent be continuously overloaded without the temperature in the windings exceeding the highest allowable. If, however, this overloading is applied when only taking note that the maximum temperature in the oil, as read on the thermometer of the transformer, does not exceed the highest permissible value, then the temperature in the windings may very greatly exceed the highest allowable value. The mean temperature of the oil by this method is certainly somewhat lower — although very slightly — but instead the temperature difference between the winding and the oil is increased proportionately to the square of the load, *i. e.* the sum of the temperature of the cooling medium and the mean temperature increase, of this and of the oil, and the mean temperature rise of the windings, exceeds the highest allowable temperature for the windings. How much the temperature of the windings exceeds the permissible value is of course dependent on the magnitude of the various temperature rises.

In the foregoing we have the whole time been considering the temperature characteristics under continuous loads. With varying loads the temperature characteristics are quite different, on account of the different heat capacity and thermal conductivity of the oil and windings. While the heat is being transferred by the oil, chiefly by the slow movement of the oil itself, transfer of heat in the windings takes place on account of the good conductivity of the copper. The temperature difference between the winding and the oil accordingly alters very quickly, when an alteration in load takes place, as compared with the value corresponding to the altered losses, while the oil temperature lags behind considerably. When the load variations are not great, it can be assumed that the difference in temperature between winding and oil is established at a definite value in five or ten minutes or an even shorter time, while the time for the oil to rise in temperature to a stationary value must be reckoned in hours. What this means if the transformer is operated from observation of the maximum temperature in the oil without regard to the actual load is quite plain without further explanation. Long before the oil has reached the permitted maximum value the temperature of the windings will have exceeded the maximum allowable value, and if such overloads occur often, or are very heavy, the winding will soon be damaged, and the insulation burnt, so that breakdown between turns, and short circuit, will soon arise.

In order to illustrate the questions dealt with above we investigate below the mathematical connection between the temperature in the oil and the windings in a transformer with two different continuous loads, and calculate an example from this. We assume the following:

Load in kVA	P_1 (normal load)	P_2
Iron losses in watts......	P_{Fe}	P_{Fe}
Copper losses in watts	P_{Cu1}	P_{Cu2}
Temperature of entering cooling medium	T_{k1}	T_{k2}
The mean temperature rise of cooling medium in °C	t_{k1}	t_{k2}
The maximum temperarature of the oil in °C	T'_{o1}	T'_{o2}
The maximum temperature rise of the oil above the mean temperature of the cooling medium in °C	t'_{o1}	t'_{o2}
The mean temperature rise of the oil above the mean temperature of the cooling medium in °C	t_{o1}	t_{o2}
The mean temperature of the winding in °C	T_{Cu1}	T_{Cu2}
The mean temperature rise of the windings above the mean temperature of the oil in °C	t_{Cu1}	t_{Cu2}

All the above hold good for continuous loading.

Putting $P_{Fe} + P_{Cu2} = (1 + k)\ (P_{Fe} + P_{Cu1})$, we obtain from the above:

$$t_{k2} = (1+k)\ t_{k1},\ t_{o1} = (1+k)\ t_{o1},\ t'_{o2} = (1+k)\ t'_{o1},$$

$$t_{Cu2} = \frac{P_{Cu2}}{P_{Cu1}} \cdot t_{Cu1}$$

Now

$$T'_{o1} = T_{k1} + t_{k1} + t'_{o1} \text{ and } T_{Cu1} = T_{k1} + t_{k1} + t_{o1} + t_{Cu1}$$

$$T'_{o2} = T_{k2} + t_{k2} + t'_{o2} = T'_{o1} + T_{k2} - T_{k1} + k(t_{k1} + t'_{o1})$$

$$T_{Cu2} = T_{k2} + t_{k2} + t_{c2} + t_{Cu2} = T_{Cu1} + T_{k2} - T_{k1} + k(t_{k1} + t_{o1}) + \left(\frac{P_{Cu2}}{P_{Cu1}} - 1\right) t_{Cu1}$$

If the transformer is worked so that the maximum temperature in the oil is the same with both loads, then $T'_{o2} = T'_{o1}$ and accordingly,

$$T_{Cu2} = T_{Cu1} + \frac{P_{Cu2} - P_{Cu1}}{P_{Cu1}} \cdot t_{Cu1} - \frac{P_{Cu2} - P_{Cu1}}{P_{Fe} + P_{Cu1}} \cdot (t'_{o1} - t_{o1})$$

Since in general t_{Cu1} is between 14 and 30 °C and $t'_{o1} - t_{o1}$ is between 8 and 10 °C, and since also $\frac{P_{Cu2} - P_{Cu1}}{P_{Cu1}} > \frac{P_{Cu2} - P_{Cu1}}{P_{Fe} + P_{Cu1}}$ T_{Cu2} must be greater than T_{Cu1}.

If also the temperature T_{Cu_1} is the highest allowable temperature in the windings, then the temperature in the windings must become excessively high, even if the maximum temperature of the oil does not exceed the permissible value.

The highest allowable overload with lower temperature of the cooling medium is determined from the equation:

$T_{Cu2} = T_{Cu1}$ from which we obtain:

$$\left(\frac{P_2}{P_1}\right)^2 = 1 + \frac{T_{k1} - T_{k2}}{\dfrac{t_{k1} + t_{o1}}{1 + \dfrac{P_{Fe}}{P_{Cu1}}} + t_{Cu1}}$$

From the above formula it follows that the larger P_{Fe} is relative to P_{Cu1} in a transformer, and the less t_{Cu1} is relative $t_{k1} + t_{o1}$, on the assumption that $t_{k1} + t_{o1} + t_{Cu1}$, is constant, the greater will be the overload capacity of the transformer.

To work up to the maximum temperature of the oil when the load is varying is still more dangerous than the case considered above with continuous overload, and this is clear from the fact that in the expression T_{Cu2} in this case T_{k2} can be assumed constant, and equal to T_{k1}, so t_{k1} and t_{o1} can be assumed practically constant while t_{Cu1} increases proportionately with the square of the output. By assuming somewhat different values for the respective symbols we obtain:

$$T_{Cu2} = T_{Cu1} + \frac{P_{Cu2} - P_{Cu1}}{P_{Cu1}} \cdot t_{Cu1}$$

The temperature in the winding is in this case much greater than in the former example, without the maximum oil temperature exceeding the permissible value. The risk is that one can considerably overload the transformer while no particular temperature rise can at first be observed on the thermometer, although the winding has reached a dangerously high temperature.

We have all the time in the above been considering the characteristics of a water-cooled transformer. In a self-cooled or forced air-cooled transformer the temperature relations are analogous, and all that has been said applies also to these types. As an example we also calculate the temperature relations in a self-cooled transformer designed in accordance with the Swedish Technical Society's rules.

In accordance with the requirements of these rules, the temperature increase of the windings and core immersed in oil is allowed to go up to 60° C above the temperature of the surrounding air, and the maximum increase in temperature of the oil above the temperature of the surrounding air can go up to 60° C in a transformer provided with an expansion vessel, and up to 55° C in a transformer without expansion vessel. The maximum temperature in the cooling medium is thus fixed at 35° C, *i. e.*, the highest temperature in the core and windings — in the last measured by resistance — may go up to 95° C, and in the oil to 95 and 90° C respectively. In general nothing is gained by making full use of the upper temperature limit for the oil, although the temperature difference

between the cooling medium and the winding is so small that the copper cannot be economically utilised. In standard transformers accordingly, the maximum temperature rise in the oil for self-cooled types is kept between 45 and 50° C and for forced cooled types between 40 and 45° C. By this means not only are the windings more economically utilised, but the life of the transformer is also prolonged, since according to our experience, working for a considerable time with oil between 85 and 90° C very considerably increases the tar formation and sludge in the oil.

Following from the figures given above, we assume that a selfcooled transformer with no load losses 1 and copper losses 2 should be constructed for a maximum temperature rise in the oil of 48° C, and a mean temperature rise in the windings of 60° C. These temperature increases hold with normal continuous full load and 35°C as the temperature of the surroundings. Assuming the mean temperature rise in the oil to be 0.8 × the maximum, which is a very good mean value, both for selfcooled and forced cooled transformers, the following values are obtained for temperatures with an output P_1 (in accordance with the above):

$$t'_{o1} + t_{k1} = 48^\circ\,C; \quad t_{o1} + t_{k1} = 0.8 \cdot 48 = 38.4^\circ\,C;$$
$$t_{Cu1} = 60 - 38.4 = 21.6^\circ\,C; \quad T_{k1} = 35^\circ\,C.$$

We now examine, partly, what output the transformers can give with a temperature of 5° C in the surroundings without the maximum temperature of the oil exceeding 95° C in accordance with the Swedish rules, and partly, the mean and maximum temperatures respectively obtained in the windings under these conditions. We have then:

$$T'_{o2} = T'_{o1} + T_{k2} - T_{k1} + k\,(t_{k1} + t'_{o1})$$
$$95 = 83 + 5 - 35 + k \cdot 48$$
$$k = \frac{42}{48} = 0.876$$
$$P_{Fe} + P_{Cu2} = (1 + k)\;(P_{Fe} + P_{Cu1})$$
$$1 + P_{Cu2} = 1.876 \cdot 3$$
$$P_{Cu2} = 5.62 - 1 = 4.62$$
$$P_2 = \sqrt{\frac{4.62}{2}} \cdot P_1 = 1.52 \cdot P_1$$

The transformer can thus be overloaded by 52 % without the maximum temperature in the oil exceeding the figure allowed by the rules. The mean temperature in the windings is, from the above:

$$T_{Cu2} = 95+5-35+0.876 \cdot 38.4 + \frac{4.62-2}{2} 21.6 = 126.9^\circ C$$

Assuming the maximum temperature of the transformer under normal full load conditions to be 13° C above the mean temperature in the windings, then the maximum temperature of the transformer on 52 % overload is 126.9 + 30.1 = 157° C. Such a temperature is absolutely ruinous to the windings of the transformer.

The figures given above apply to continuous load. With variable load the only difference is that the transformer can be overloaded considerably more for a shorter time without the oil temperature exceeding the permissible value. The mean temperature of the winding and the maximum temperature then considerably exceed the values given above in a shorter time.

In order to guard against the dangerous overloads mentioned, it is necessary to use some temperature indicator on the transformer, with a signalling arrangement, and showing the maximum and mean temperature in the windings. By embodying a thermo-element in the windings themselves at the hottest point, a good temperature control can be obtained, but this arrangement is not to be recommended from the manufacturing point of view as it is bound to endanger the working of the transformer. It will be born in mind that the thermo-element must be connected to earth in order to make it possible for a reading to be obtained from it. Accordingly the thermo-element in the windings must be electrically insulated, and this necessitates that it is also to some extent thermally insulated from them. Its functioning on rapidly changing load is accordingly rather uncertain. With the higher working voltages it is practically impossible to provide, and satisfactorily insulate, such an element, and we do not recommend the arrangement in any case.

As we stated before, the temperature in the windings is made up of the sum of a temperature increase proportional to the square of the load, and the mean temperature of the oil, so that it might be thought possible to place a thermometer in the hottest part of the oil, so arranged as to be affected not only by the oil temperature, but also by the load current. The reading given by the thermometer should then be the sum of a reading depending on the maximum temperature of the oil (*i. e.* practically proportional to the mean temperature of the oil), and a reading depending on the square of the load, and accordingly proportional to the temperature difference between the oil and the windings. This last reading should have a time lag in order to take account of the heat capacity of the windings. Such a temperature indicator must be calibrated for each transformer. We have at the present time under construction such a temperature indicator which we hope to be able to place on the market before long. The apparatus will, however, be somewhat expensive, as it is necessarily of a rather complicated nature.

CONSIDERATIONS IN DESIGNING FURNACE TRANSFORMERS.

In a foregoing article some of the points of view of the manufacturer have been given regarding the heating and load characteristics of transformers in general. We now intend to touch upon those questions effecting the design of transformers for furnace work in particular with respect to the output for which they are designed.

During the years in which we have manufactured furnace transformers, we have on several occasions, when carrying out repairs and alterations to various makes sent us by customers, had the opportunity of very carefully investigating these points on transformers which had been in service for longer or shorter periods. We have noticed during these examinations that a number of these transformers have had their insulation damaged in a way which indicates that they have been exposed to dangerous heating. The insulation was, in general, found to be damaged in all parts of the windings and in many cases it had been uniformally charred. Ordinary power transformers which we have had the opportunity of examining after being some time in use have only in very exceptional cases shown such deterioration. Having regard to temperature rise and overload capacity, it appears usual to construct ordinary power transformers and furnace transformers on the same principles. Our observations, however, show that power transformers and furnace transformers for the same nominal outputs should *not* be designed for the same temperature rise and overload capacity. Furnace transformers must be more liberally dimensioned than other transformers. We intend here to indicate why and to what extent.

In order to clear up these questions it is necessary to appreciate the reason for the dangerous heating which has resulted in damaging the insulation. As it has been observed that the circulation of the oil through the windings in the burnt-out transformers has not been lowered to any considerable degree, the reason for the difference in various transformers must be sought in the service to which they have been subjected. Furnace work normally gives rise to overloading. The first thing that comes to mind is that transformers may be continuously overloaded when delivering their full output while the temperature of the cooling medium is low, and this load persists until the oil temperature reaches the permissible limit. The result of this, as we have mentioned in a former article, is that the transformers are burnt-out after being in use for some time. Another reason may be that although the regulation of the voltage and the furnace electrodes is carried out in such a way that the external load on the transformer is as nearly as possible equal to the output for which the transformer is designed, still owing to short circuits in the furnace, and overloads of short duration, which often arise, the transformer is considerably overloaded as regards its windings, even if this does not show in the oil temperature. This kind of overload has also been dealt with in the foregoing article.

In polyphase installations another cause of overloading may be dissymmetry of various kinds. This may be caused directly due to the furnace leads for the different phases being differently arranged and giving rise to alteration in reactance, but may also be caused by a transference of power between different sets of furnace leads (these acting as a transformer). This may take place particulary in cases where the phases are connected together to a neutral point at the transformer and each phase is taken to the furnace by only one group of conductors. Also, in cases where the start and finish of each phase is taken to the furnace by conductors which are well laminated, mutual induction is obtained between phases if these are run too close to one another. These effects have been understood for a considerable time and we overcome them as far as possible, although there are still installations at work with the furnace leads unsuitably arranged, and it is not possible to overcome dissymmetry entirely even when designing a new plant. These unsymmetrical effects are, however, of great importance to the satisfactory working of the transformer. This holds good whether the transformers used are singlephase and Scott connected, or threephase, although in singlephase transformers, with separate regulators for each transformer, the working can be so arranged that there is no risk of burning out from this cause. In general this depends upon how the regulation of the power delivered is effected, and if there is a transforming effect between phases one phase will then be considerably more heavily loaded than the rest — cases have arisen where 30 to 40 % of the power of a transformer per phase has been transferred to the other phases. That this results in overloading of one phase of the transformer which gives up this extra amount of power is evident. It is therefore necessary to determine if any considerable inductive effect between different phases is taking place.

It will be clear from the foregoing that there are briefly three reasons for the fact that furnace

transformers of unsuitable design are more often damaged or burnt out than is the case with ordinary power transformers. Which of these can be made to furnish a definite specification must be determined by co-operation with the users. We are glad of every opportunity of assisting and obtaining information jointly with our customers, which can be employed to clear this matter up completely. Apart from the actual cause, however, we are certain that furnace transformers, when designed in a way which is analogous to that used for designing power transformers, and calculated with the same temperature rises and overload guarantees, will give rise to trouble through overheating.

It is not sufficient when ordering furnace transformers to specify merely the voltage, capacity, system of connection, and continuous output required, and these particulars are very often the only ones which are given. In exceptional cases only requirements regarding overload capacity are stated. It is essential when sending replies to our standard question sheet for furnace transformers, and upon which the design will be based, that full information be given concerning duty and operation, and not only the percentage overload anticipated, but also the duration of such overload. Only by this means can we offer transformers of a suitable character. It is quite certain that the standards usually adopted for power transformers are quite inadequate and unsuitable for furnace work.

To what extent the overload capacity of furnace transformers requires to be increased so that one can be quite certain that no damage will occur in normal working, is naturally a question which has to be settled in each individual case. Any standard rules regarding the overload capacity of such transformers would be of very great use, but, at the same time, their importance would be wholly illusory, if the normal full load output of the transformers was not correctly and definitely specified, in relation to the furnace installation under consideration, and the load characteristics required by it. A determination of load characteristics for different types of furnaces, of various sizes and uses, provided with hand and automatic regulation for the electrodes, would accordingly be of considerably value. Such a determination should be based upon load curves obtained from plants already installed, and would result in standard load diagrams, from which the nominal power necessary for a given furnace could be estimated, with full regard to the ability of the furnace transformer to deal with the varying loads.

Such a research could only be undertaken by actual users of electric furnaces, and would certainly be of great interest both to the manufacturers and purchasers of electric furnace plants. We on our side would be very glad to assist by supplying all the information regarding temperature characteristics and load characteristics of transformers for furnace work which would be necessary.

RIKSGRANSEN—NARVIK TRANSMISSION LINE, NORWAY.

The electric power for the line known as the Ofoten Railway from Riksgransen to Narvik is supplied from the Swedish State Power Station at Porjus as single-phase alternating current at a pressure of 80,000 volts. The power line for the Riksgransen Railway has been extended from the Vassijaure transformer station to Riksgransen and there connected up with the Norwegian transmission line.

The work of transporting the material for this line was commenced in the beginning of March 1922, the weight to be carried amounting altogether to about 400 tons. The transmission line runs partly over very awkward country, over desolate mountains and sheer precipices, and over deep valleys, so that the transport was attended with very considerably difficulty.

Fig. 1. Transporting cable over the Kvitur Mountains in April 1922.

As there was exceptionally little snow on the montains, the necessary ironwork arriving very late, most of the parts for the masts were carried out to their positions on men's shoulders. The masts were delivered in sections, and arranged for fitting together on site. Only the cross arms, weighing about 110 kgs, were supplied welded up. In a number of places the parts for the masts had to be lowered hundreds

of metres into their places for erection, and a number of sites were absolutely inaccessible until late on in the summer when the snow and ice had disappeared.

All the masts are four-sided, with a 3-metre base and a foundation for each upright. The height of the masts varies, and a number were supplied 14, 16, 18 and 20 metres high.

The rivetting up and erection of the 177 masts was completed by about the 1st September.

The transmission line crosses the railway at five places where specially strengthened supporting arrangements and double chains of insulators are used. The lines are crossed over at four points.

The two copper conductors each have an area of 60 mm² and are supported by strain insulators each with six sections. The conductors are drawn up to special straining masts, and at these points seven insulator sections are used in series. The earth wire is clamped to the top of the cross arm, and consists of a galvanised steel cable having an area of 35 mm².

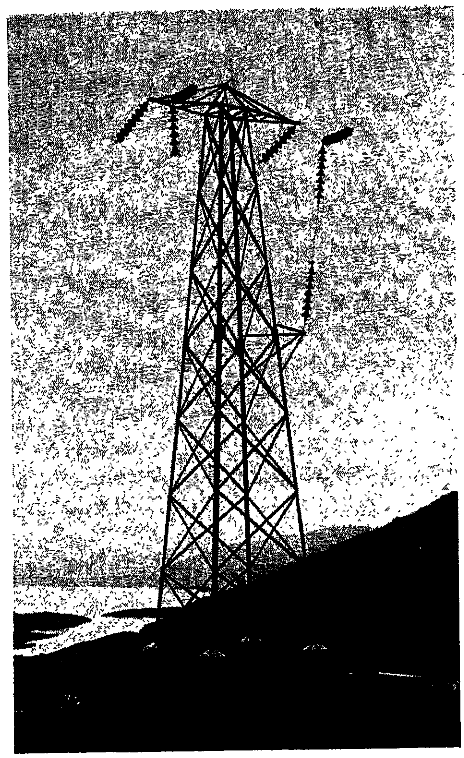


Fig. 2. Crossover point.

The length of the transmission line is roughly 35 kilometres, and the longest span about 455 metres across the Sildvik River. The sag amounts to 53.5 metres at this point, at a temperature of 25° C. For this span two masts have been placed at one end at a centre distance of 36 metres, each carrying one conductor. This construction is adopted to prevent the lines on this long span swinging into contact with one another during stormy weather, and causing a short circuit.

An interesting test of an 18 metre supporting mast was undertaken: a foundation was placed close to a vertical cliff so that horizontal stresses could be produced by means of pulleys fixed to the cliff wall. Three weights were attached in this way to the mast, one representing the weight of the conductors themselves including snow and ice loading, one representing the wind pressure on the conductors and cross arm, and one representing the wind pressure on the mast. The first named weight was attached to the top of the mast at its centre point, the second weight was also placed at the top of the mast, and the third at a section approximately in the middle of the mast, with the load divided evenly among all four uprights by a special sling.

The loading was carried out with cast-iron weights, guided in a specially constructed framework, and increased successively while readings were taken with a theodolite of the displacement of the top of the mast.

The erection of the conductors on the transmission line was commenced in the middle of July, and the work was completed ready for inspection and testing within the contracted time, by the beginning of November.

In spite of the particularly difficult characteristics of the country referred to above, no serious accident occured during the installation.

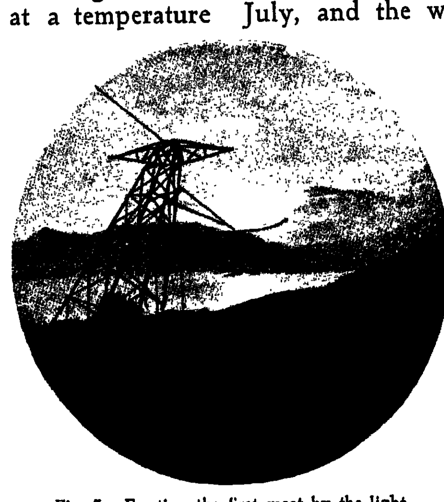
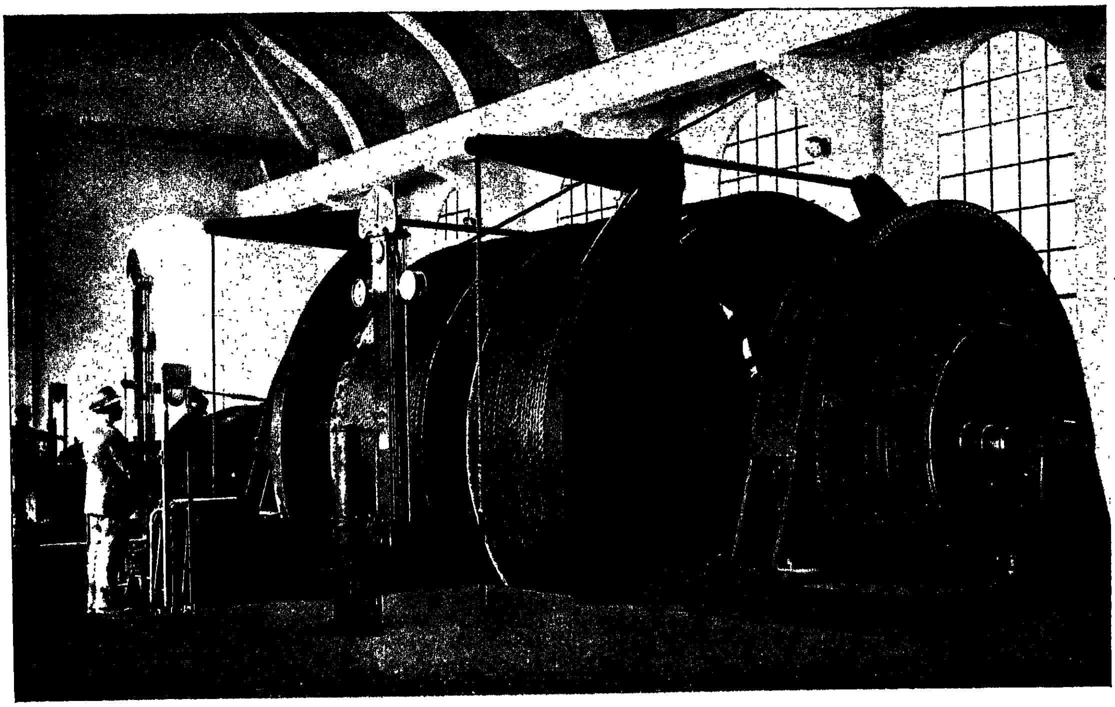


Fig. 3. Erecting the first mast by the light of the midnight sun, 15th June 1922.

WINDER FOR THE ORKLA MINING CO., NORWAY.



Large electric winder for Wallenberg Pit, Lökkens Verk, Norway.

Asea recently supplied the electrical parts for the largest winding gear in Scandinavia, installed by The Orkla Mining Co., Norway. The winder, the mechanical parts of which were supplied by Holmens Foundry & Mechanical Works, Nyby Bruk, is installed at the Wallenberg Pit and is designed for lifting a nett load of 5 to 6 tons per wind in a vertical shaft having a depth of 540 metres, the maximum winding speed being about 7.2 metres per second.

The driving motor is divided into two series connected DC motors, each direct coupled to one of the two drums of the winder. The diameter of these drums is 4.6 metres. (See illustration above). Each part of the motor is designed for a continuous output of 350 h.p. at 300 volts and ± 30 r.p.m., so that the total continuous output is 700 h.p. at 600 volts. The winding motor is connected on the Leonard system to an Asea-Ilgner set consisting of a three-phase induction motor of 750 h.p., 3,000 volts, 50 cycles, a DC generator of 580 kW, ± 600 volts, 730 r.p.m. and to a double flywheel weighing approximately 18 tons.

Both the winding motors and the Ilgner set generator are excited from a separate motor driven exciter at 220 volts.

For limiting the power taken from the supply network to a value corresponding to the mean power required during each wind, the Ilgner set motor is provided with an automatically operated secondary liquid resistance which is constructed on the principle which embodies stationary electrodes and circulating electrolyte.

The same resistance serves as a starter for the Ilgner set.

Vesteras 1925, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

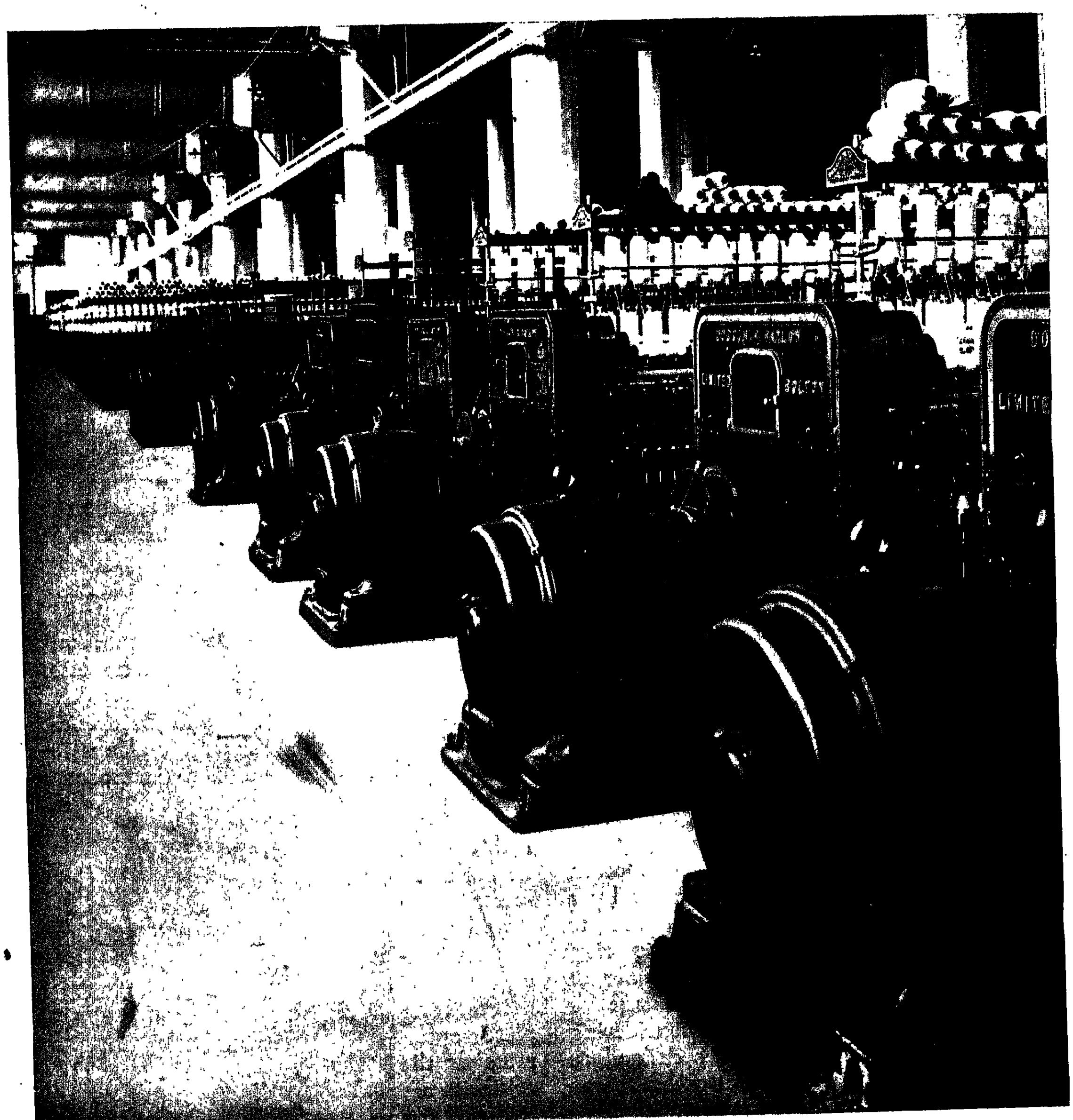
ALLMÄNNA SVENSKA
ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

VOL. II
1925

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesterås, Sweden.

MARCH-APRIL
Nos. 3-4



Asea single phase commutator motors 9.5 h.p., 950 r.p.m., 25 cycles, with automatic speed regulation, driving ring spinning machines.

MOTOR EQUIPMENT IN THE ELECTRICALLY DRIVEN COTTON MILL.

An exhaustive treatment of the problems encountered in the motor equipment for an electrified cotton mill cannot be given within the scanty limits of one of these articles. This article is also written with the object of giving a brief review of present practice as regards motors and apparatus of suitable design for different installations, so as to meet the working conditions and the various regulations drawn up by local authorities and fire insurance companies. We now propose to further limit the field by considering the plant required in the cotton spinning industry, and all that we have to say applies more or less to the textile industry in general, as the processes through which the raw material has to go are to some extent the same in any branch which may be considered. Several illustrations applying more particularly to the manufacture of wool are accordingly included in this article.

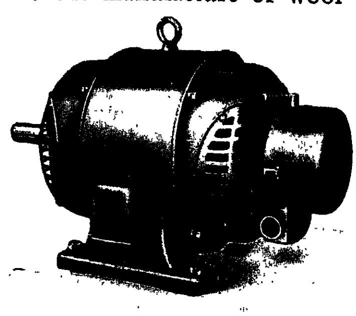


Fig. 1. Open-protected three-phase motor type MK with enclosed sliprings.

From the time it reaches the mill in bales, until it leaves as finished thread, cotton passes through a number of processes which can be divided into cleaning, carding and drawing, twisting, fine spinning, and various finishing processes. Each of these main groups covers a number of different processes, so that the divisions which we have introduced above are quite arbitrary, although they lend themselves to a consideration of the questions referred to regarding the electrical equipment.

At the present time alternating current is practically the only supply in question, both on economic and technical grounds. The possibilities of speed regulation with small losses which can be obtained with continuous current motors, can in nearly all cases be obtained equally well by the use of modern AC commutator motors, and an attempt which was lately made by a foreign firm of electrical machinery builders to reintroduce the DC motor for driving ring spinning machines, gave rise to a number of objectionable results. As regards the voltage for distribution, it may be taken when considering new installations, that the pressures defined as "low tension" should not be exceeded without some very special reason, and in most cases standard voltages such as 380, 220 or 190 should be used. On account of the large number of small motors which are in question, if the supply voltage is taken higher, both the cost of the installation and the charges for power will be increased, the latter on account of the reduced efficiency which would be obtained from the motors.

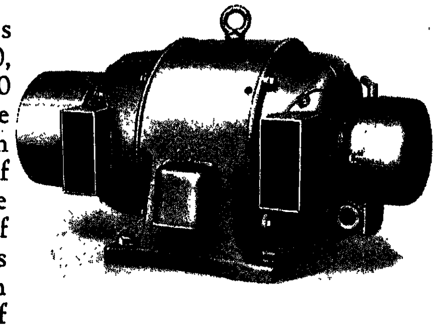


Fig. 2. Pipe-ventilated three-phase motor type MK.

Regarding the construction of the machines and apparatus the requirements of the insurance companies are fully met:

a) As regards motors for opening and cleaning — — — mixing, and in waste and scutching rooms — — —

if the casing of the motor is of iron, and airtight, or provided with openings for ventilation only, and arranged so that the circulation of air takes place through fireproof pipes and is drawn from, and discharged to, the open air, or some locality which is free of dust.

b) As regards motors for other localities where inflammable dust is present, for example, cotton, wool etc.,

if the motor is a squirrel cage induction motor, *i.e.* without sliprings, or is of the arrangement provided as specified under a), or if sliprings are provided and totally enclosed in a dustproof cover;

and further as regards starters and regulating resistances in localities such as described under a) or b) above,

if all moving contacts, and in the case of localities as mentioned under a), also all resistance material is enclosed in a dustproof cover of suitable non-inflammable material, or if immersed in oil;

and as regards switches,

if the complete apparatus or the contacts are enclosed in

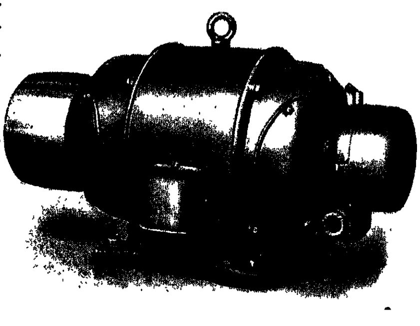


Fig. 3. Totally enclosed three-phase motor type MK.

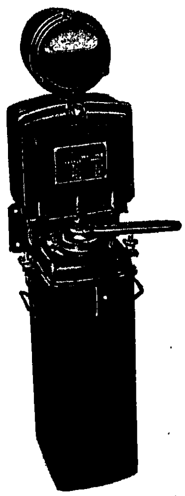


Fig. 4. Combined starter and main switch type PSC for slipring motor.

an airtight cover of incombustible material.

Returning to the classification given above for the different processes of manufacture, it can accordingly be laid down that all motors used in the cleaning processes must be made totally enclosed or pipe ventilated, whether they are of slipring or squirrel cage design, while for other localities there is a wider choice in the selection of a motor. Here open type motors may be used if they are furnished with squirrel cage rotors, open type slipring motors with the sliprings enclosed, and also, of course, pipe ventilated or totally enclosed motors, like those specified for the cleaning processes. When possible squirrel cage motors are to be preferred from the point of view of first cost, and also because these machines cannot be bettered as regards low upkeep charges and safety in running. The limit to their use lies in their starting characteristics. While on the one hand their starting current is relatively large — on switching on direct with full voltage the short circuit current of the motor is obtained at the instant of switching in — and on the other hand the starting torque is not particularly high. For outputs up to 3 h.p., however, if there are no special requirements to be considered, it is not usual for anything to be considered beyond a motor of standard open type with squirrel cage rotor, and in many cases very much larger squirrel cage motors can well be used, e.g. for driving short lengths of shafting which are started light etc. To assist in the selection of a motor, approximate values are given in the table below for the starting torque and starting current of motors of the most usual small sizes when switched direct on to the line, the starting current being given as a multiple of the normal full load current. By the use of star-delta starting, the starting current is reduced to 58 %, and at the same time the starting torque falls to 33 % of the value given when switching on to full voltage direct.

The values below, which apply to motors of Asea's make, are considerably more favourable than are advised by the Swedish Electrical Standards Committee regarding starting requirements for squirrel cage motors.

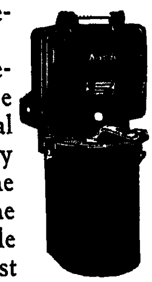


Fig. 5. Starter type KKS for squirrel cage motor.

A slipring motor, by suitably designing the starting resistance, can be made to give a starting torque equal to the full load torque without any considerable rush of current at the moment of starting. According to the Swedish Rules it should be possible for this torque to go up to at least 175 % of the normal.

Coming to starting apparatus it may be remarked that the market is flooded with a large number of different designs, many of which are very far from meeting the rules referred to above, and a good many of which constitute an actual danger to any installation. Asea has always been in the front rank of all developments of a sound and practical nature in apparatus construction, and accordingly has a complete range of standard starting apparatus which can be relied upon to operate faultlessly, and fully meet the working conditions found in electrical installations for textile plants. Regarding apparatus which should be used in cases already referred to, it may be said that starters for motors used in the cleaning processes should be oil immersed, both the contacts and the resistance itself being under oil. Starting switch cases combining primary switch, with overload protection, and secondary starter, consititute a simple and cheap arrangement, besides preventing incorrect operation during starting. They can in general be made suitable for motors up to 40 h.p. and have been used by Asea with entire success in all the localities referred to.

Changeover switches for squirrel cage motors,

R.p.m. Synchronous	3,000		1,500				1,000		750			
Cycles	50		25		50		50		25		50	
h.p.	Starting torque	Starting current	Starting torque	Starting current	Starting torque	Starting current	Starting torque	Starting current	Starting torque	Starting current	Starting torque	Starting current
0.5	1.7	4.2	1.8	4.0	1.7	4.0	—	—	—	—	—	—
1.0	1.7	4.4	1.8	4.2	1.6	4.2	1.4	3.6	—	—	—	—
2.0	1.6	4.6	1.7	4.4	1.6	4.4	1.4	4.0	1.4	4.0	—	—
3.0	1.6	4.8	1.7	4.8	1.5	4.6	1.3	4.2	1.4	4.2	0.9	3.8
5.0	1.5	5.0	1.6	5.2	1.4	4.8	1.3	4.4	1.2	4.2	0.9	3.8
10.0	1.5	6.0	1.6	5.8	1.1	5.2	1.0	4.8	1.0	4.4	0.8	4.0

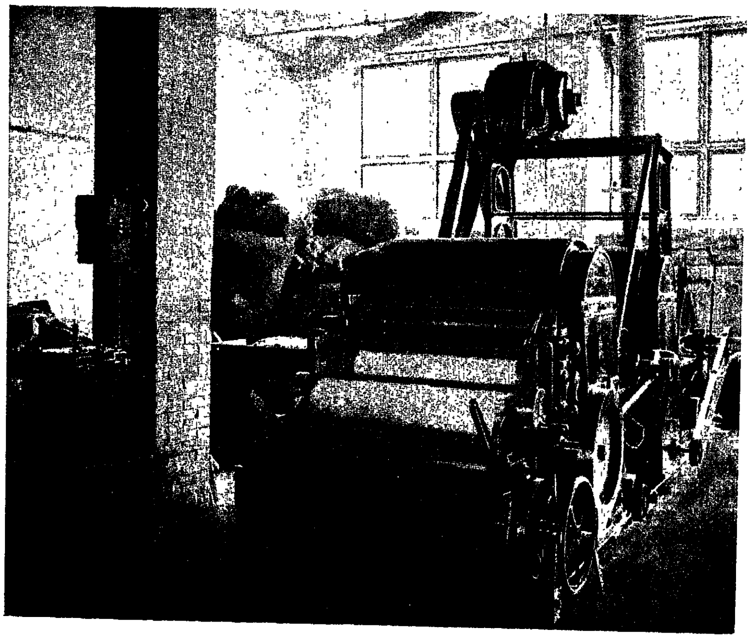


Fig. 6. Individual drive of opener.

while double or combined machines require eight to ten horse power, vertical openers, "Crighton Openers" about eight horse power. Belt drive, with the motor placed on the ground is used in many cases; modern machines are often furnished with a driving axle, designed to run at a standard induction motor speed, 725 or 950 r.p.m., in which case the motor is direct coupled to this driving axle, by means of a flexible coupling, and at the same time, a small saving is effected, by eliminating the transmission losses in the belt. In such cases the Crighton opener is provided with a vertical direct coupled motor, and the flexible coupling must be to some extent special by designed so as to permit a vertical movement of the driven shaft of the opener amounting to 10 mm or so. As we have stated

whether for switching the motor direct on to the line, and furnished with special contacts for cutting out fuses during starting, and so permitting an effective protection of the motor, or for star-delta starting, and made totally enclosed, with contact arrangements immersed in oil, more than fulfil all the requirements.

A description of the various apparatus, distribution boxes etc., of enclosed ironclad construction and arranged with connecting boxes for tubing or cables, which go to make up a modern properly designed motor installation, would take up a great deal too much room. It is sufficient to say that experience shows that capital expended in having all these details of suitable design is certainly well employed.

The machines given under the head of "cleaning" in our foregoing division of the processes are bale breakers, openers and beating machines, which are all used for the purpose of opening out and cleansing cotton. All these machines have properties, as regards construction and method of working, which are best suited to the use of a separate motor for each machine, — individual drive. A bale breaker requires from two to four horse power, depending on its construction, and openers and rotary beater machines take four or five horse power in single units,

above, all these motors should be either totally enclosed or pipe ventilated, and the latter arrangement often comes out more expensive, in spite of the lower motor price, on account of the cost of the ventilating ducts, more especially in the case of motors of small size.

Carding machines, to which the cotton is taken after the cleaning process, are slow running machines having a driven shaft speed of 160 to 190 r.p.m. The power required per machine is about one horse power. Carding engines run continuously, and owing to their large rotating

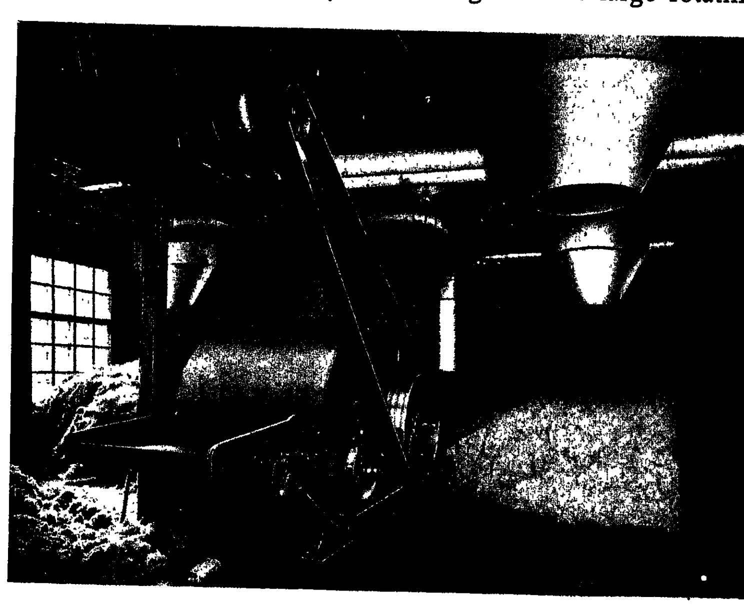


Fig. 7. Individual drive of carding engine.

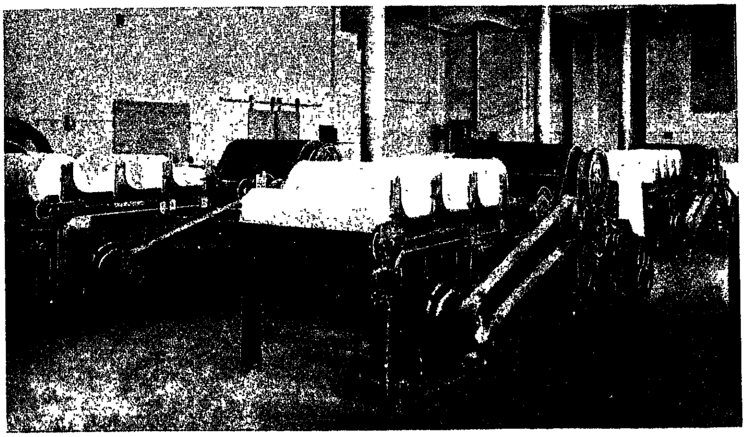


Fig. 8. Rotary beaters.

masses, their starting conditions are somewhat heavy. All these characteristics, small power, continuous and even running, and heavy starting conditions, indicate the use of group drive. The speed of the line shaft should be taken at about 250 r.p.m. and a further speed reduction made between the motor and the shaft. In order to eliminate another belt drive the motor for this work can be furnished with a self-contained reduction gear, and the slow running shaft end direct coupled to the line shaft. The remaining machines comprised in this group for drawing and doubling the "slivers" have also low power requirements, and slow running driving shafts, and all that has been said regarding carding machines also holds for them. The positions in which all these motors are used, are exposed to an atmosphere full of cotton dust, so that if the motor is hung from the ceiling or in some other way which makes regular cleaning out of the windings difficult, it is advisable to instal totally enclosed or pipe ventilated machines, although this should not be interpreted to mean that machines of this construction are absolutely necessary. Individual drive of machines in this group can be employed, but is hardly justified without some special reason, as for example, where the ceiling is low or the roof construction too light to withstand the strain of the countershaft. An exception to this rule may possibly be made also in the case of drawing and doubling machines which may be profitably arranged for individual drive when it would otherwise be necessary to instal separate line shafting for them. It is, then advantageous to use standard loom motors designed for belt drive, and provided with spring tension adjusters, and the automatic operating arrangement can in general be easily combined with the motor switch.

As the fibres of the material are, practically speaking, parallel during the above-named processes, and the material is in narrow strips (slivers), further drawing out cannot be accomplished without twisting them to some extent so as to obtain a higher tensile strength. This twist is given in fly frames and we must distinguish between slubbing, intermediate, roving and jack frames, through which the rough cotton passes in the order named, undergoing continual drawing and spinning. The power requirement per spindle is highest in the heavy slubber, and at the same time the spindle speed is lowest in this case. In order to determine the power required it is usual to reckon 50 spindles per horse power for a heavy slubber, 60 for an intermediate slubber and 70 to 80 for a fine slubber. These figures may be taken as being good medium values, and err somewhat on the side of safety. From an estimate which we recently made on a number of shaft driven groups of slubbers (Dobson & Barlow type 1915—1916) we obtained a nett power requirement of 1.0 kW per heavy slubber with 92 spindles, and 1.25 kW per intermediate or fine slubber with 160 spindles, corresponding to 68 and 94 spindles per horse power respectively. In general, at any rate in

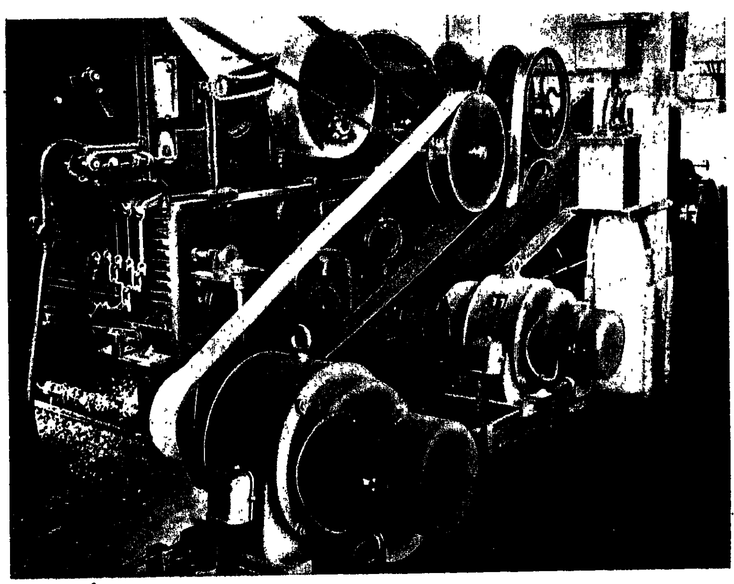


Fig. 9. Cleaning and mixing room in wollen mill.

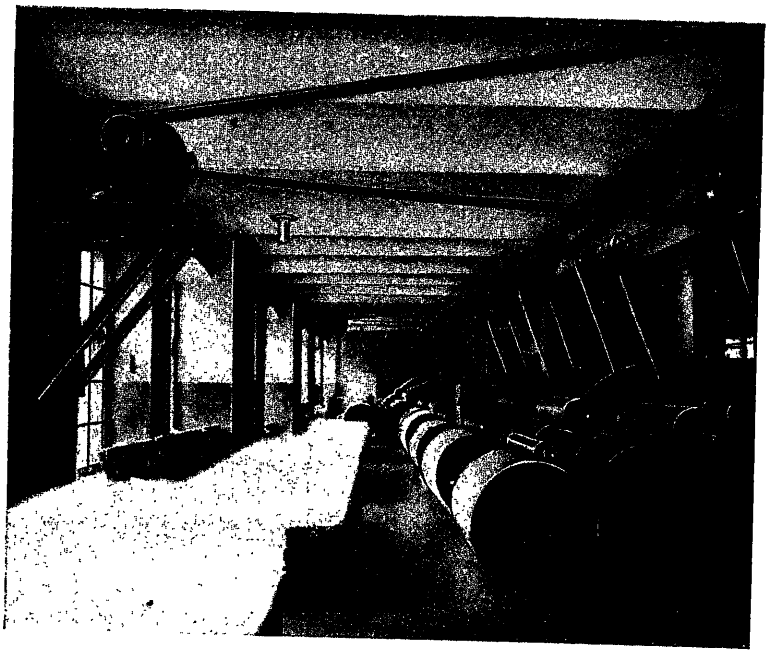


Fig. 10. Group drive of carding engines.

Sweden, slubbers are driven from a common line shaft, or in groups from a number of separate lines of shafting.

Individual drive, if it can be arranged so as to meet the working conditions properly, undoubtedly possesses a number of advantages, and there is at the present time a general tendency towards the adoption of such drives wherever possible. A simple, but at the same time highly satisfactory, solution of this particular drive problem is to retain the belt drive with fast and loose pulleys, and to furnish each slubber with a separate squirrel cage motor mounted on the top of the frame. This motor is then started on no load, and the belt thrown over in the usual way by means of a dog. On account of the shortness of the belt, and as the drive is a vertical one, these motors are mounted upon a pivoted frame so that the tension of the belt can be kept at a suitable value by means of an adjusting screw. Another arrangement to secure the same result is the use of an idle pulley, and this is also made to take the place of the dog for shifting the belt.

Since the cotton at this stage has a very low tensile strength, as we stated above, it is very necessary that starting shall be particularly slow and even to avoid breakages. With the arrangements referred to above, a sufficiently even start is obtained, due to the slipping of the belt when it is changed over from the loose to the fast pulley. In cases where the motor is direct coupled to the slubber driving axle, the starting problem has given rise to a number of complicated constructions which permit an adjustment of the starting torque of the motor to a suitable value. These arrangements, which consist in the provision of special "leakage rings" on the rotor, have been regarded by textile manufacturers as being too difficult in operation, to judge by the small application which the devices have found. A somewhat similar result as regards the possibility of adjusting the starting torque of the motor, can be obtained in a less complicated manner, as for example, by suitably combining a primary starting resistance with a clutch, or still more simply by using a motor with exactly correct starting torque. As the driving axle of a sluber only has a running speed of about 300 to 500 r.p.m., the motor may be connected to it through gearing, and in general arrangements are made for easily altering the gear ratio so as to alter the speed of spinning to suit the degree of fineness or coarseness desired. The clutch for the direct connected motor is operated by a rod running the whole length of the machine, and

Fig. 11. Individual drive of slubber with fast and loose pulleys.

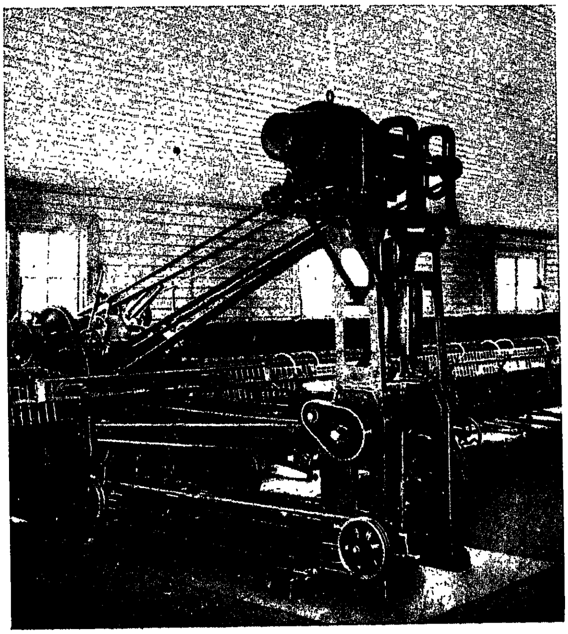


Fig. 12. Individual drive of self-acting spinning frame for wool.

is arranged so that it permits the machine to be instantly brought to a standstill when required in order to join up a broken yarn. The motors for individual drive of slubbers are furnished, as we have stated before, of the squirrel cage pattern and in the open arrangement. For motors for group drive, which may be provided with self-contained reduction gears for direct connecting to line shafting, the same remarks hold good which have been made for group driving carding machines.

Fine spinning of the cotton thread, after the preliminary processes in the slubbers, is done by two different methods, spinning on self-acting mules and ring spinning, of which the latter, as far as cotton is concerned, is much more widely used, although spinning on self-acting mules is retained practically always for spinning the finer counts.

As spinning on self-acting mules is a discontinuous process, the power requirements vary for the different phases of the cycle. As these variations are besides very considerable, the problem of driving demands special attention. The schematic diagram (fig. 13) shows the power requirements over one working period for a self-acting mule with 832 spindles, and having a spindle speed of 6,000 r.p.m. On the same diagram is shown the total power requirements for four similar machines driven as a group from a common motor, under the assumption that the ideal arrangement is obtained, the machines running so that the peak loads of each machine are evenly divided over a working period. Even with these particularly favourable conditions, which are never obtained in practice, or at least cannot be obtained for a long period, it is seen that the load on the driving motor is particularly variable. In order to decrease the percentage variation in the power requirements with group drive, other machines are often driven from the line shaft which drives self-acting mules, such as carding machines. which have an even load, and constitute a steady basis for the load on the transmission system. With individual drive it will be obvious from the diagram that a motor is necessary which has a very high overload capacity with reference to its normal output, and which has a high efficiency even at low loads. In order to compensate to some extent for the greatest peak loads, which occur when the self-acting mules run in unison, the use of a flywheel on the motor has become usual. It is unquestionable that such an arrangement smooths out the load, but at the same time, when energy is taken from the flywheel, the speed of the motor must be decreased somewhat. As an average power requirement for self-acting frames, when spinning cotton, it is usual to take one horse power to 110—130 spindles, depending on the count etc., but this figure is not very definite and is hardly

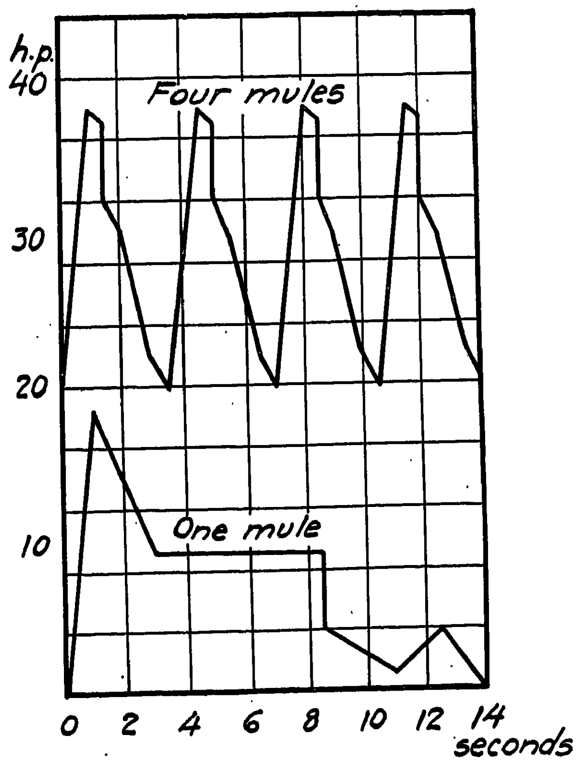


Fig. 13. Diagram showing power requirements of self-acting spinning mules.

good enough for determining the sizes of motors for individual drive.

It will be apparent, from what we have said above regarding the variation in the load, that a motor furnished for individual drive must always be specially designed in order to meet the requirements which arise under working conditions.

Ring spinning on the other hand is a fully continuous process. The working capacity of a ring spinning frame is also greatly superior to that of the self-acting mule, and at the same time the amount of space taken up by the machine is considerably less. A short description of the method of working of this machine must now be given, in order to assist in explaining the question of suitable drive. The spindle arrangement on a ring spinning frame is shown diagramatically in fig. 14. The twisted yarn passes through the drawing rollers A where the rolls rotate at different speeds so as to give a suitable amount of stretch to the rough yarn, which is afterwards led through the eye B and the traveller L to the rotating spindle D. The traveller can move freely on the ring R which surrounds the spindle. As the spindle rotates at a definite speed, the traveller, on account of the tension in the thread, is obliged to follow the rotation of the spindle although at a somewhat lower speed due to innertia. The yarn is accordingly wound up on the spindle at a speed corresponding to the difference between the spindle and traveller speeds, and at the same time it is given a twist or lay, the number of turns corresponding to the speed of the traveller. In order to make the subsequent unwinding of the yarn from the spindle easier the cotton is wound on the spindle in conical layers. As the number of turns in each layer is made different, the threads in addition cross over one another. All the rings R are arranged upon a common frame, the ring frame, which can be raised and lowered. The crossing of the layers of thread is obtained by making the time for raising the frame about three times greater than the time for lowering, by which means a correspondingly greater or less number of turns are wound up. After each period in the movement of the ring frame it is raised by an amount corresponding to the thickness of the layer of thread which has been wound on. As the traveller L is carried round by the rotation of the spindle a force is required, the direction of which at each instant coincides with the tangent to the ring R at the point where the traveller happens to be at the time. This force, which is proportional to the speed of the traveller, is a component of the tension in the thread between the traveller and the bobbin. As

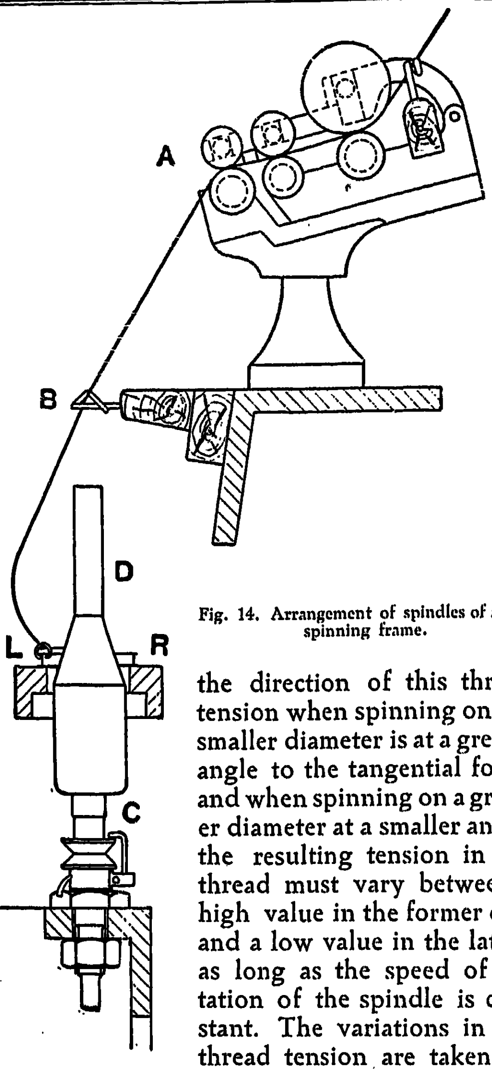


Fig. 14. Arrangement of spindles of a ring spinning frame.

the direction of this thread tension when spinning on the smaller diameter is at a greater angle to the tangential force, and when spinning on a greater diameter at a smaller angle, the resulting tension in the thread must vary between a high value in the former case and a low value in the latter, as long as the speed of rotation of the spindle is constant. The variations in the thread tension are taken up in the "balloon" of cotton formed by that part of the thread which lies between B and L, and which, on account of centrifugal force, is curved outwards into a flying balloon when the spindle is running.

For driving ring spinning frames two different methods are in general used. One of these gives a constant speed to the frame and causes variable thread tension, and the other gives a variable speed to the frame, and is arranged so that the thread tension remains constant. In the first case, however, the speed must be so low that the thread tension at its highest value does not exceed the allowable tensile stress for the thread, while in the second case, when spinning at a variable speed and constant thread tension, it will be clear that the speed of spinning is the medium speed and the production is accordingly higher. The spindles are driven by cords from a sheet-iron cylinder, the tin roller, which is carried on the driving axle of the frame and rotates with a speed of from 500 to 1,000 r.p.m. When individual drive is used the motor is direct coupled

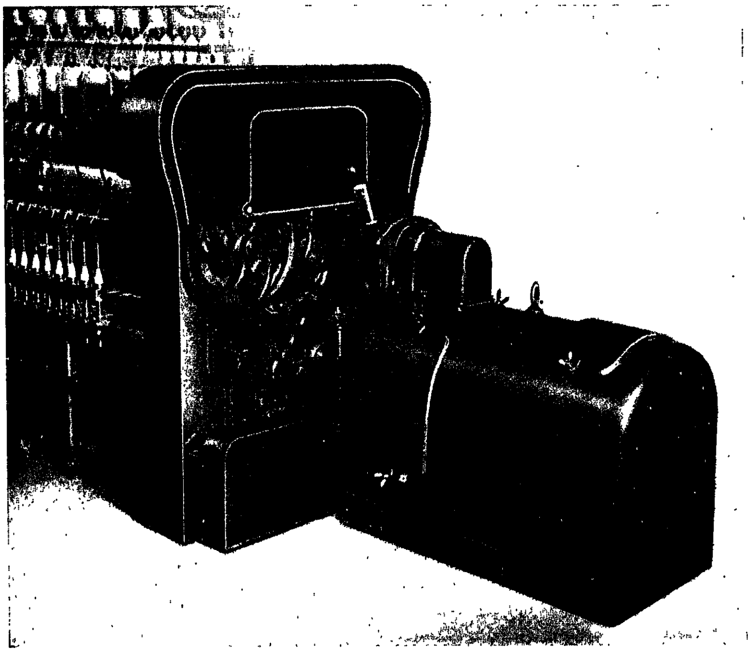


Fig. 15. Asea three-phase commutator motor driving ring spinning frame.

to this shaft or else the motor itself is provided with an extended shaft which is made to carry the tin roller. Further, reduction gear between the motor and the driving shaft can be used, or else belt drive from a motor mounted on the spinning frame.

For drive at constant speed, open type squirrel cage motors are used almost exclusively, and for variable speed drive AC commutator motors which are then made of ventilated enclosed pattern. As an intermediate system between constant speed and variable speed drive, there is an arrangement which makes possible a speed reduction at the beginning and end of the spinning period, at those points where the thread tension is greatest. Such regulation can be obtained with slipring motors by means of a series resistance, but this method of regulation is uneconomical since the speed reduction obtained means a corresponding increase in the power lost in the resistance, the percentage increase being the same as the percentage drop in speed. Such regulation can also be obtained by using a motor designed to run at two speeds, for example, in the ratio of 8:6, or by a mechanical arrangement making use of the slip in the belt in the belt drive transmission between the motor and the driving axle, or finally also by using a variable speed commutator motor, similar to that used for giving a variable speed drive.

Variable speed commutator motors are made both single-phase and three-phase, and the former type has been adopted in most cases on account of its relatively more simple construction compared with that of the three-phase motor. The single-phase commutator motor has shown itself to be very suitable in a large number of cases, but on account of its series characteristic it is sensitive to voltage and load variations — the speed variation is, practically speaking, proportional to the alteration in supply voltage or load — so that Asea has undertaken in addition to this construction a three-phase commutator motor having shunt characteristics, and in which the above drawbacks are eliminated. Speed regulation with both constructions is carried out in the same way by shifting the brushes on the commutator of the motor, and this method is, practically speaking, free from losses. For fixing the speed which is to be the basis of running, and for altering the speed when necessary by hand, the motor is provided with a handwheel for moving the brush rockers, and for the automatic speed regulation the regulating mechanism on the motor is combined with a separate spinning regulator driven from the spinning frame, and in which, according to Asea's construction, the movement of the spinning frame is determined by cams which operate the brush shifting gear in a manner corresponding both to the lowering in speed required at the beginning and end of the spinning period, and

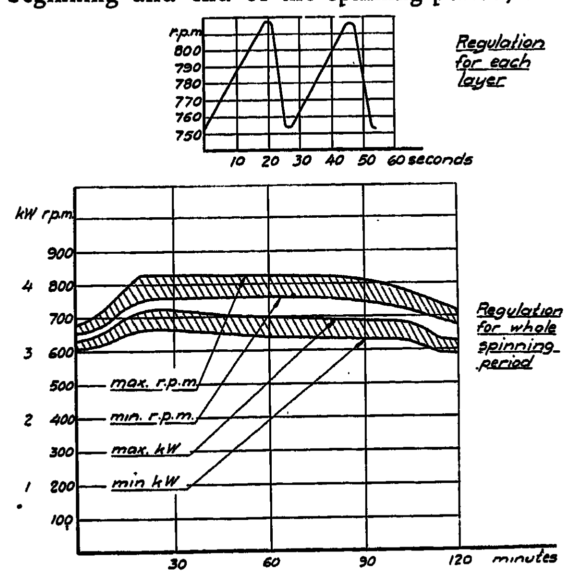


Fig. 16. Diagram showing regulation and power requirements for a 304 spindle Dobson & Barlow spinning frame for 30' cotton, with automatic speed regulation.

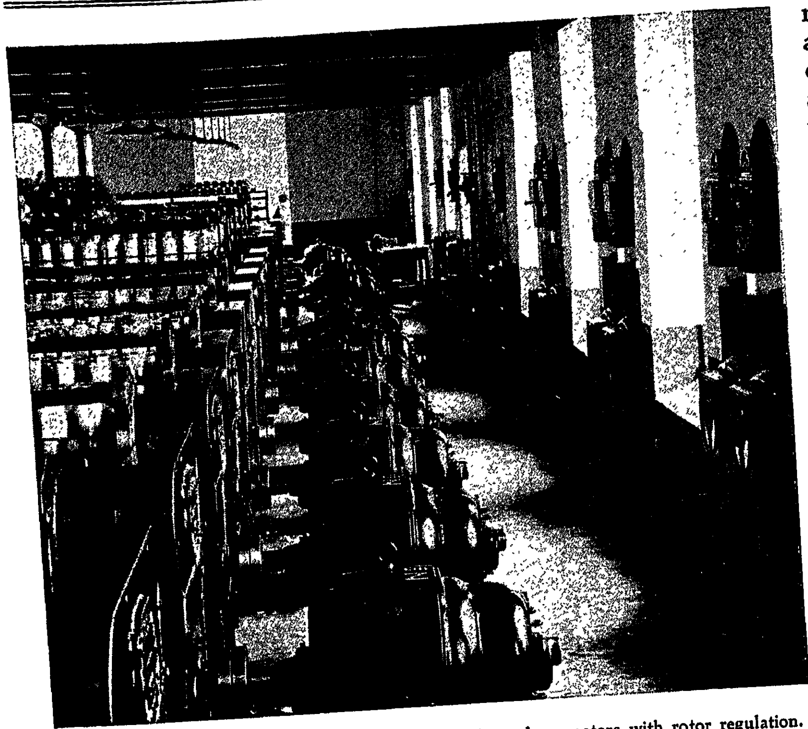


Fig. 17. Ring spinning frames driven by slipring three-phase motors with rotor regulation.

also in such a way as to give the variable speed for each layer of thread corresponding to the diameter of the bobbin, on which winding is taking place at any instant. A primary switch is also built into the motor for operating purposes, so that no separate starting arrangement is required.

The spindles rotate with a speed which is commonly between 6,000 and 10,000 r.p.m., according to the fineness of the cotton being spun, although speeds which are higher or lower sometimes occur. The power required principally depends on the speed, and for a preliminary estimation can be assumed to be as follows:

With a spindle speed of 8,000.
1 h.p. for 70 to 80 spindles.
With a spindle speed of 9,000.
1 h.p. for 60 to 70 spindles.
With a spindle speed of 10,000.
1 h.p. for 40 to 50 spindles.

From tests recently made on a Dobson & Barlow spinning frame driven by Asea commutator motors, it was found that for 424 spindles when spinning 24 cotton at a constant speed of about 8,600 r.p.m. (835 r.p.m. on the tin roller), a nett power of 6.6 h.p. was taken, or 1 h.p. for 65 spindles, and for another frame spinning 30 cotton with about 7,900 r.p.m. (768 r.p.m on the tin roller), 7.7 h.p. was taken, or 1 h.p. for 74 spindles. For a 304 spindle frame spinning 30 cotton with about 8,500 to 7,800 r.p.m. with automatic speed regulation (825 to 755 r.p.m. on the thin roller), 3.7 h.p. was required, or 1 h.p. for 82 spindles.

Individual drive of ring spinning frames and its advantages as regards production and the quality of the work turned out has been dealt with in a very large number of articles, so that the question will not be taken up and discussed further here. There is such a great advantage in driving by means of motors with speed regulation, on account of the possibility of using the same frame without any alteration for spinning cotton of widely varying counts, that every spinning mill should have some frames at least driven in this manner, in order to obtain the flexibility of production which is always required in order to be able to meet a sudden demand for any particular number.

The finishing processes for the cotton which leaves the fine spinning frames consists of winding, reeling, cop winding etc., and a number of other operations which do not in general require any mechanically driven machines.

Twiner doubling is done in machines which are generally built on the same principle as ring spinning frames, and accordingly all that has been said above regarding the driving of such equipment applies here also. The power requirement is higher than for ring spinning frames. Machines for cop winding, and reeling require a relatively small amount of power, and the speeds of their driving axles vary considerably for different constructions. The drive is, in general, done in groups from a common countershaft, and in cases where individual drive is considered more suitable it can usually be arranged without any particular difficulties being encountered.

ELECTRIC DRIVE OF LOOMS.

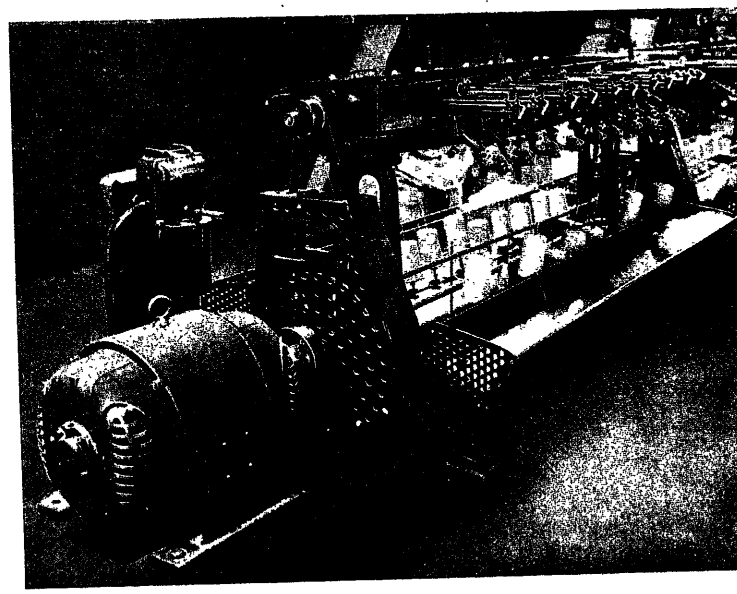


Fig. 1. Winding machine driven by MK motor.

The equipment in a weaving shed consists comonly of reeling and bobbin winding machines for the warp and part of the weft, warping, sizing and beaming machines.

Although the power requirements are not great, it is necessary to pay particular attention to the drive of all these machines, as any fault in this respect reacts upon the whole weaving process, increases the running costs and lowers the quality of the material produced.

For all these machines individual drive is particularly suitable, for spool winding machines because they have to be stopped very frequently, and for warping and beaming machines because they take up a lot of space, and it would be a costly matter to drive a number of them by shafting. Winding machines (fig. 1) can be driven by belt or gearing at a constant speed. For small powers totally enclosed loom motors are accordingly used, and for larger outputs open type squirrel cage motors can be employed in certain cases. Starting is effected by switching the motor straight on to the line by means of the special loom motor switch type SB 320, or by a change-over switch type KKS which allows the fuses to be cut out during starting.

Warping machines are provided with self-contained mechanism for speed regulation, so that constant speed motors can be used for driving them. The machines are driven by belt or through a double reduction gearing, and the same motors and apparatus which are suitable for spool winding machines can be used for them (fig. 2). Sizing machines, which are in general combined with beaming machines, are driven by belting from a standard slipring or squirrel cage motor, or alternatively they can be provided with a direct coupled commutator motor with a gear which simplifies the driving mechanism considerably. In the latter case the speed regulation required is obtained without introducing any losses simply by moving the brush gear of the motor.

For driving the looms themselves electrically, a choice has to be made between group drive and individual drive.

With group drive it is sometimes possible to run all looms in one room from a single motor, or alternatively several line shafts may each be run from their own motor. In the first case the main shaft is commonly operated from the motor by a chain drive, and in plants where it is particularly desired to reduce the losses which are inseparable from the use of belting, the intermediate shafts are also driven in the same manner. If only two shafts are to be driven this can be done direct by chains from the motor, which is then placed between the two shafts and hung from the roof (fig. 3). When only one shaft is to be driven from the motor the best solution is to direct couple a motor provided with reduction gear, to the line shaft, as by this method smoother running and a more compact arrangement is obtained (fig. 4).

Motors for group drive are commonly furnished of the open type with enclosed sliprings, or else of the core-cooled type. When the motor is supported from the roof, the starter, which is fixed on the nearest wall or pillar, is provided with an interlocking contact so that incorrect operation of the brush lifting and short circuiting gear is obviated.

In all these cases the looms themselves are belt driven and the drives are nearly vertical from the line shafts which in general run at a somewhat higher speed than the looms. The losses due to slipping of the belt on these relatively long drives are reckoned to amount to from 6 to 8 % according to mean values which have been obtained from various tests.

With group drive the looms can be driven by belts or gearing from special motors.

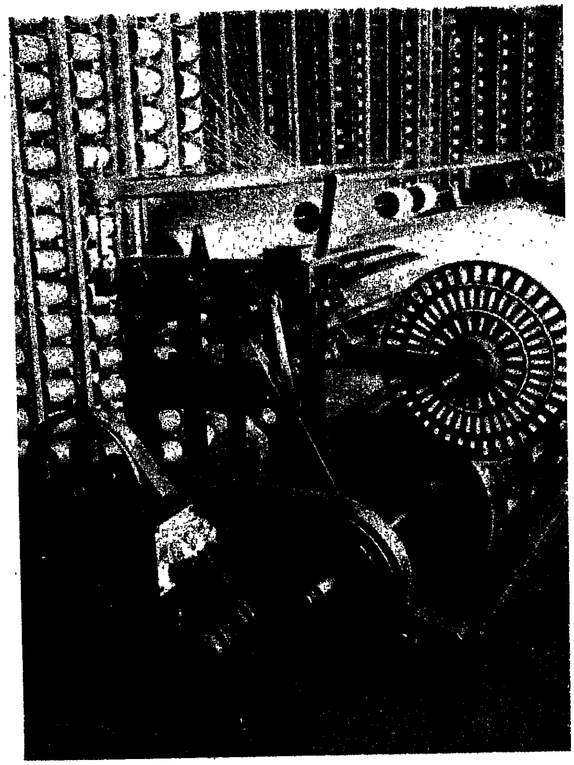


Fig. 2. Individual drive of warping machine.

and is gained by eliminating the belt slip. At the same time the running of the loom is much more certain than it is with individual drive through a belt, since a belt always runs differently when the dampness of the air changes, and conditions in this respect in the weaving shed may vary widely at different times of the year and even at different times of the day.

It is generally known that the individual drive of looms is more economical than line shaft drive. In weaving sheds where individual drive is installed it can be stated that the increase in production amounts to 10 to 25 %, depending on the higher efficiency and the increased speed of the looms which can be allowed owing to the smoother running. At the same time the saving in power has been estimated to be from 10 to 20 % and this again is due to the elimination of the practically indeterminate friction and belt losses which occur with shafting transmission drive.

That the speed can be increased is shown beyond all doubt by the tachograph diagrams. There is no reason to prevent a gear driven loom running with the same medium shuttle speed as a loom which is group driven, and at the same time with 10 % lower maximum speed and above all with smaller strains in all parts of the loom itself and the material. It can be

In figure 5 are shown tachograph diagrams taken on both plain and automatic looms driven by different methods. These clearly show that much more even running is obtained with individual drive and gearing than with belt drive. It can be seen further that on starting up a loom driven through gearing the start is much quicker and the normal cycle of the loom is carried out much more rapidly than with belt drive.

Everyone acquainted with textile work knows how important it is to secure constant speed for the machines in order to maintain good quality and high production, although naturally the speed should not be absolutely constant over the whole working period but should be arranged so that a certain fixed speed corresponds to each instant in the period of working. The tachograph shows that it is possible to secure this with individual drive, and that with plain looms which often require to be stopped for changing the shuttle, the gear drive has considerable advantages over belt drive. With automatic looms, which only require to be stopped occasionally, and with which the running time can reach 80 or 90 %, the starting qualities of the gear drive is of less importance; instead, however, there is another advantage, due to the saving in power which may amount to 4 or 5 %

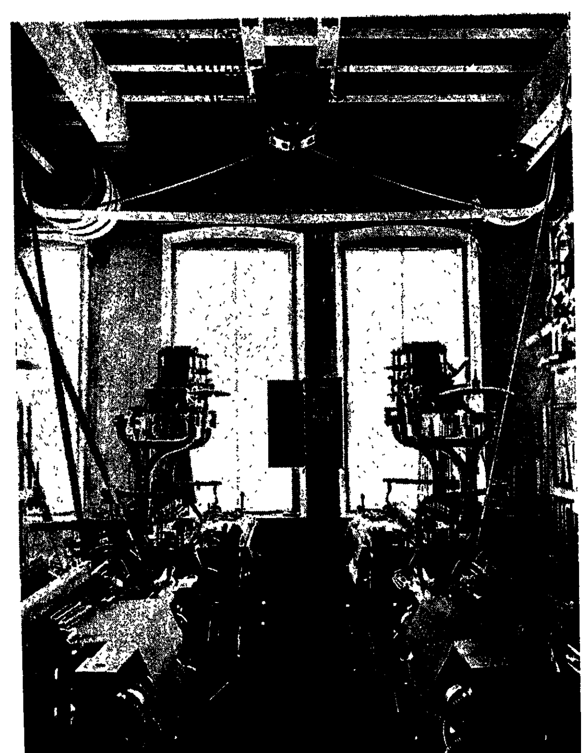


Fig. 3. Group drive of looms through silent running chains.

assumed that practically the same maximum speed can be maintained without causing the thread to break or the strains in the machine to be greater. This corresponds to an increase in production of 11 %. From some manufacturing statistics taken with such looms with individual drive, and group drive, it has been established that the efficiency $= \frac{\textit{actual shuttle speed}}{\textit{highest possible shuttle speed}}$ is about 75 % with individual drive and 70 % with group drive, *i. e.* a further increase in production of 7 % with individual drive, so that the total possible increase in production in the case considered is 18.7 %.

When making comparisons regarding power requirements it is of course necessary that exactly similar looms must be compared when weaving the same material, since the power taken varies considerably with different weights and widths of material. According to the latest measurements which were made on a Northrop loom a mean power requirement of 0.305 kW with individual drive and 0.36 kW with group drive was obtained, and when these measurements were taken the number of passes of the shuttle per hour was 7,650 and 7,140 (mean values over a considerable running time). The power required per 1,000 passes was thus in one case 0.0399 kW and in the other case 0.0504 kW, accordingly there is a saving of 21 %.

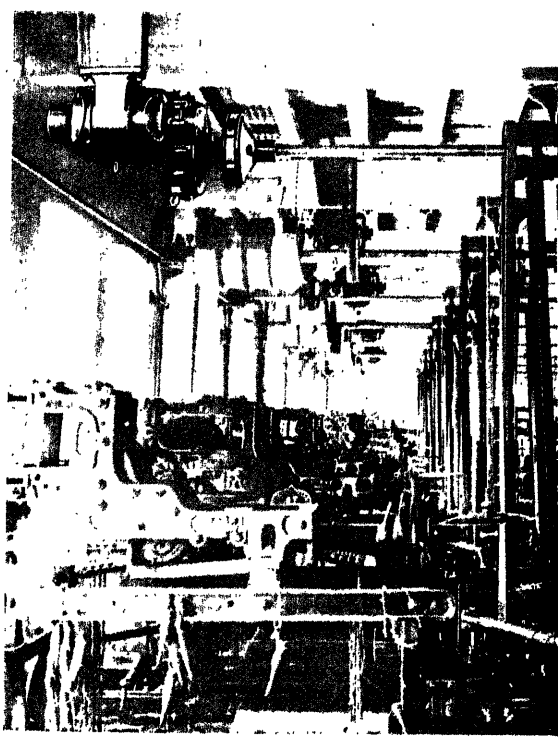


Fig. 4. Group drive of looms. Geared motors direct coupled to line shafts.

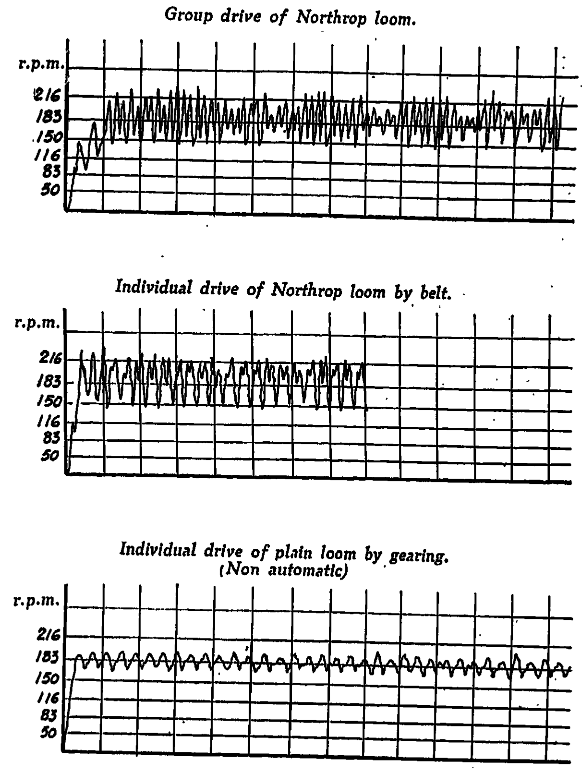


Fig. 5. Tachograph diagrams for looms.

Individual drive not only possesses the advantages stated above, but makes possible a great improvement in the lighting, cleanliness and general appearance of the plant, due to the elimination of the belt transmissions. It is only necessary to indicate the advantages an indirect or semi-indirect lighting scheme for a weaving shed with high candle power lamps, can afford in comparison with the very unsatisfactory light obtained with individual lighting from a number of small lamps. This question is particularly important in weaving coloured material of a dark tint, as due to insufficient lighting there is often a considerable loss of time in looming. The advantages of the individual drive are such that when a new installation is being considered the individual drive is the only one which can come into the question, since the saving which would be effected by using transmission drive shafting is offset by the lighter roof and pillar construction which can be used, and accounts for the greater part of the increased cost which individual drive requires in comparison with group drive. At the same time it must be kept in mind that the advantages which are obtained with individual drive, consisting of increased production and improvement in quality of material, can only be obtained by some increase in the cost of the installation.

It is another question when we come to existing installations. Here transmission shafting schemes already exist and the buildings are specially arranged for them. The installation of individual drives accordingly necessitates a considerable capital outlay. Can this be justified? This depends entirely upon the circumstances under which one is working. The installation of individual drives will most certainly result in considerably increased production with the same buildings and arrangement of looms, and can accordingly be a very satisfactory way of meeting a projected extension of the drive. On account of the more even running, the looms will not depreciate so rapidly and the operating costs will be reduced. As each loom is complete in itself the greatest possible flexibility can be obtained in the most economical way by the introduction of gear drives. Although the power costs are only a small part of the total working costs (5 to 10 %), still the saving in this direction which is introduced by individual drives is well worth taking into consideration.

For individual drives Asea has brought out special types of motors for belt and gear drive, and in the latter case for looms of different makes. In addition two different motor types are made, the one having a particularly high efficiency and power factor, and the other a cheaper machine with normal efficiency and power factor. Which of these types is most economical in any case depends upon the cost of power. Figure 6 shows the efficiency, power factor and starting characteristics for a 0.5 h.p.

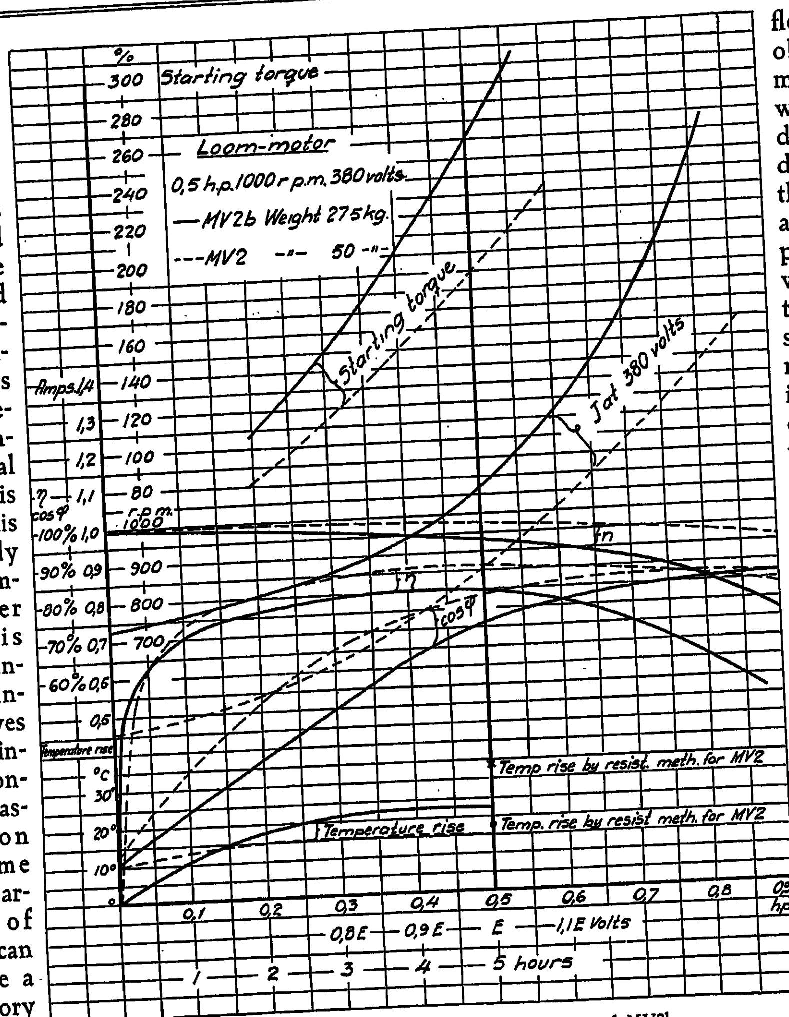


Fig. 6. Characteristic curves of loom motors MV2 and MV2b.

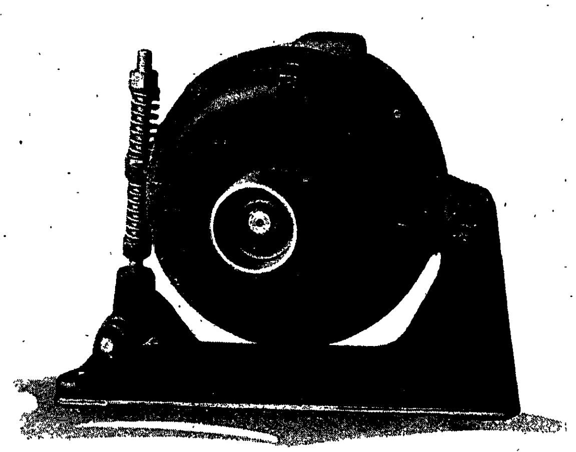


Fig. 7. Loom motor with tension arrangement, arranged for vertical drive.

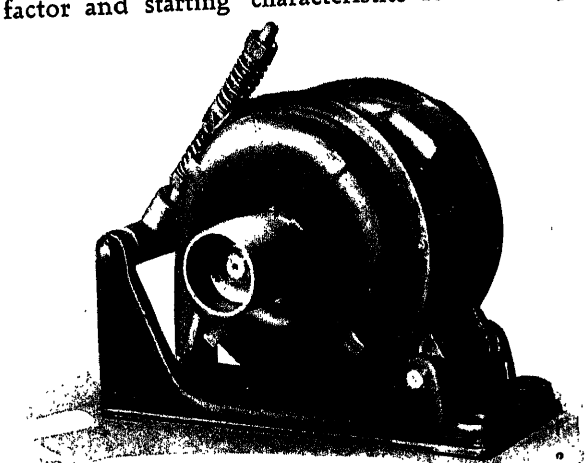


Fig. 8. Loom motor with tension arrangement, arranged for horizontal drive.

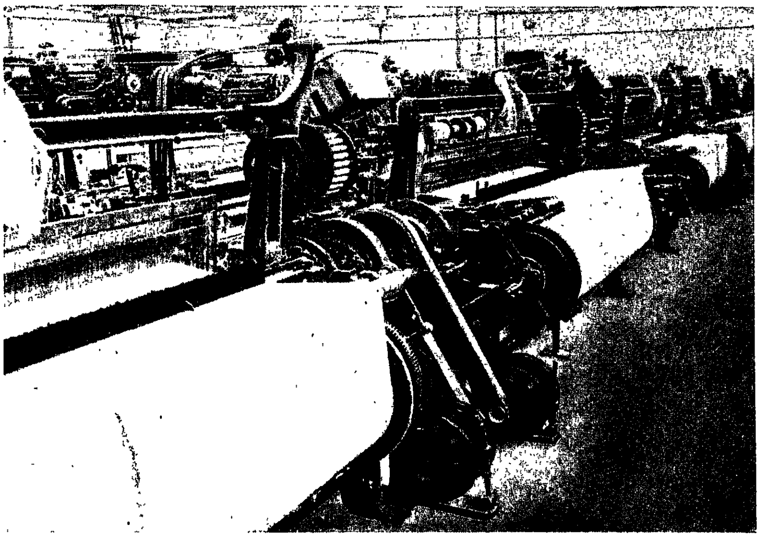


Fig. 9. Individual drive of Northrop looms. Belt drive.

motor. It is to be noted that the efficiency is practically constant between half load and full load, so that on the very variable load given by a loom a high mean value is obtained. Under present conditions it is found that with a price for power under 0.8 d. per kW hour it is cheaper to use a motor with normal efficiency, while with a higher price for energy the more expensive motor is advantageous.

Individual drive with belts.

Loom motors are normally constructed totally enclosed and usually for a speed of 960 r.p.m. on 50 cycles. The stator is provided with two lugs for supporting the motor in a belt tightening arrangement. The rotor is of the squirrel cage type and the copper bars of the rotor are rivetted into the short circuiting rings so that contact is obtained without the use of solder or welding. They have amply dimensioned shafts, with free shaft ends, and ball bearings are used. Figure 7 shows the manner of mounting these machines in the belt tightening arrangement for vertical drives, and figure 8 shows the arrangement for horizontal drives. The last arrangement is commonly used when the motor is to be supported on the wall. It can accordingly be used without alteration for all types of loom and takes up an exceedingly small space.

Two springs counterbalance the motors own weight, and the elastic suspension protects the loom against vibration and shocks. The same type of motor can be used for most of the other machines in the weaving shed, such as winding machines, warping machines, sizing machines etc.

Figure 9 shows the motor in use with a Northrop loom.

With belt drive it is not desirable to use a higher ratio than 1:5 or 1:6 between the motor and the loom, as in other cases the angle subtended by the belt at the motor pulley is too small, and accordingly large losses occur owing to slipping, while starting is unsatisfactory. With larger looms, having a low spindle speed, lower motor speeds can be chosen, or a reduction gear can be adopted. Idle pulleys on the belt, which in the case of other machines allow large ratios to be used, cannot be permitted for looms. If the loom stops with the shuttle in the middle of its stroke very heavy strains occur when the belt is kept tight with an idle pulley which may cause breakage of the shaft or frame.

Individual drive with gearing.

Gear drive, which was at first only furnished for slow running looms (less than 160 passes per minute), was shown to introduce such advantages in respect of efficiency and smooth running that it soon came into general use for higher speeds also, and displaced belt drive more and more. This has been contributed to

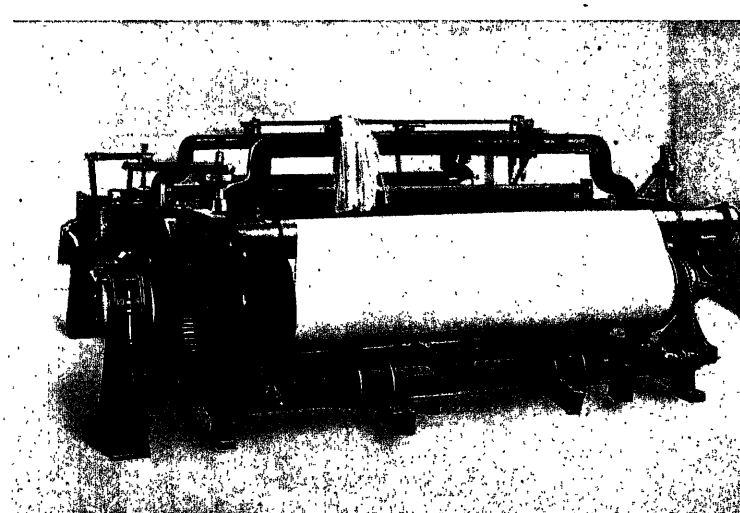


Fig. 10. Individual drive of Northrop looms. Gear drive.

by the fact that the difference in first cost in comparison with individual drive by belting is very small, and the depreciation of the gear wheels, which have a long life owing to the smooth running which takes place with the shock absorbers described below, is less than that for belts, and in addition, as we have already pointed out, an absolutely definite speed is obtained at the loom without constant supervision.

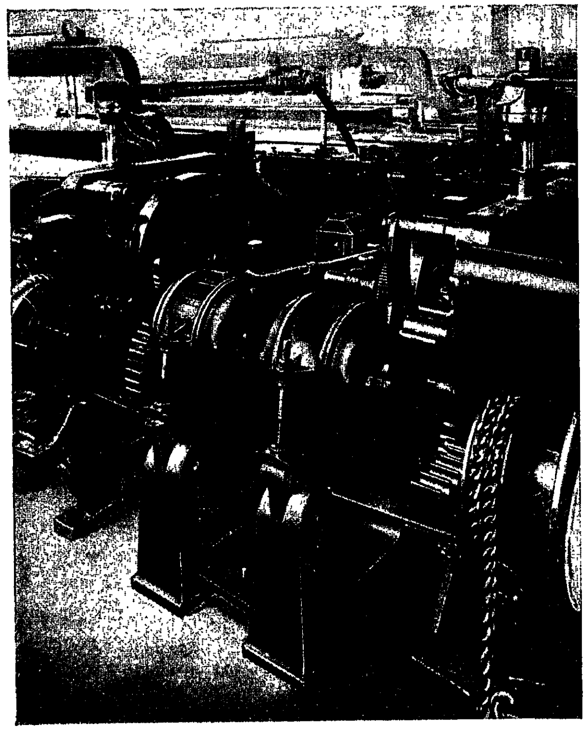


Fig. 11. Loom motors with gears and slipping clutches, mounted upon looms.

As we have mentioned in connection with belt drive, there may be enormous strains in the gears when the loom is suddenly stopped due to the inertia of the moving parts of the loom, and to the flywheel effect of the motor. In order to limit this value, the problems introduced were studied at a very early stage in the construction, and the large gear wheels have been made of the elastic pattern by embodying spiral springs between the rim and the hub. This was not entirely satisfactory and resort was soon made to a friction coupling between the rim and the hub. It was quickly apparent that metallic friction surfaces were unsatisfactory in the relatively damp atmosphere of a weaving shed. For friction surfaces a material must be used which does not rust, and the coefficient of friction of which does not alter under varying atmospheric conditions. Such a material is hard wood or fibre, which has been used for a long time for similar couplings on wool looms and in other industries where a damp atmosphere is met with.

The construction used by Asea is shown in figures 10 and 11.

In a solid cast iron frame which carries the bearing for the driving axle of the loom, a motor is fixed in such a way that the centre distance between the motor and the driving axle is adjustable. By using different gear wheels the shuttle speed of the loom can be altered. The frame is so built that motors for right and left hand looms can be placed side by side so as to take up the least possible axial length. Besides this the motor is free and can be easily changed if this should be necessary. The gear wheel, which is carried by the loom driving axle is arranged with friction arrangement, limiting the power which can be transmitted

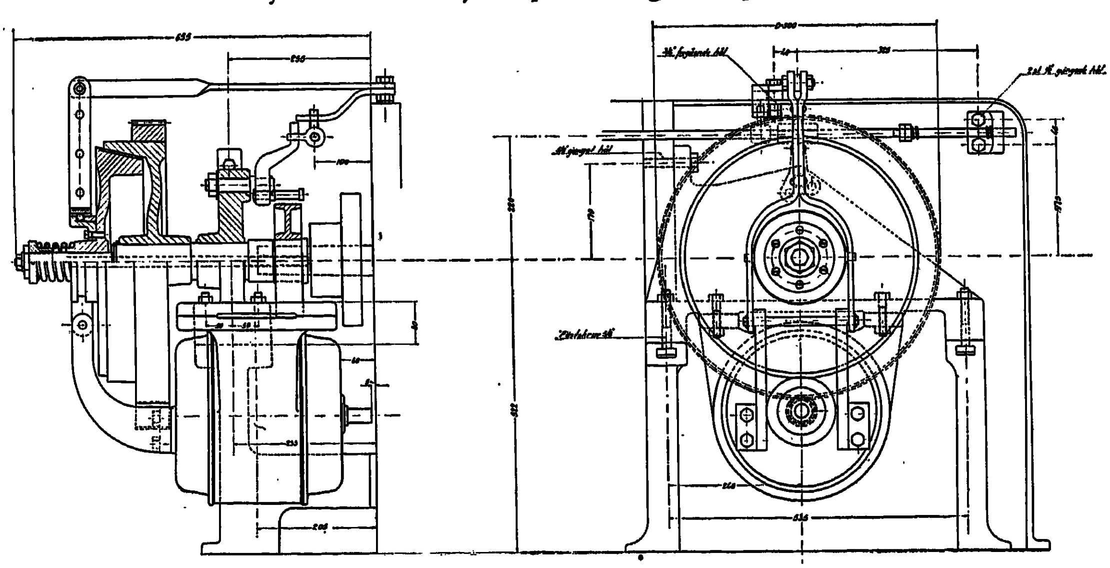


Fig. 12. Arrangement for individual drive of heavy loom. Gear drive.

through it. This consists of a cylindrical brake drum, which is keyed on to the driving axle of the loom, and upon it a brake band, faced with wood, which in its turn is fixed to the toothed rim. The last is suitably carried so as turn easily round the brake drum. The pressure of the brake band on the brake drum is secured by two strong spiral springs which can be easily regulated so that the coupling is sufficiently resistant to meet the torque necessary for starting the loom but slips if this amount of power is exceeded. In this way no excessive strains occur in the gear wheel or loom. When the loom is stopped the coupling slips, and the flywheel effect of the motor is braked down.

For heavy looms for wool etc., Asea, after careful trial, has introduced a special construction which is particularly robust. In this construction, which is shown in figure 12, the friction coupling already described has been used, and the drive is direct on to the loom axle by single reduction gear. For braking the loom a powerful brake arrangement is fixed on the loom driving shaft. The motor is supported direct on the loom and drives through a friction coupling fixed to the toothed rim. As this part of the coupling can be turned on the loom shaft the motor can be connected before the fixed part of the friction coupling engages, and starting is thus made easier.

The motor is switched direct to the supply by the loom switch shown in figure 13, and which is type SB 320, supplied without fuses. We recommend that fuses should be placed in the distribution boxes arranged for a number of looms, otherwise they must be dimensioned for the individual starting current, making them considerably overdimensioned for normal working. The switch is interlocked with the operating gear of the loom in such a way that the weaver is able to stop both the loom and the motor with the same handle.

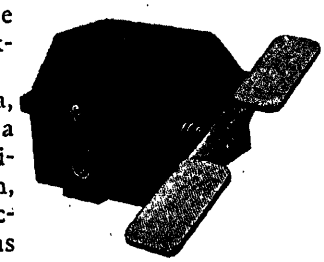


Fig. 13. Loom motor switch.

INDIVIDUAL DRIVE OF COTTON PRINTING MACHINES BY VARIABLE SPEED AC MOTORS.

Roller printing machines, on account of the great output that can be obtained from them, have practically displaced other methods for the mass production of printed cotton goods. The construction which has been adopted is so adaptable that all the particulars given below regarding individual drives with variable speed AC motors hold good equally well for nearly all types of machines found on the market.

The effects which are obtained in weaving by the use of different coloured yarn, are obtained quicker and more cheaply by printing. In printing the colours sink into the fibres of the material in the same way as a dye, so that the printing of cloth can be defined as a complicated example of dyeing. The roller printing machine works with rotating metal rolls, upon which the pattern is engraved. The material to be printed is run together with a felt guiding band, and a protecting cloth for this, between the above rolls and rotating cast iron cylinders, the number of these being determined by the number of colours which are to be used. The engraved cylinder is filled with colour from a cloth covered wooden roller in contact with it which revolves in a colour trough while a spring steel scraper removes from its surface all the dye which is not absorbed in the material covering it. The fully printed material is dried on heated rolls as soon as it

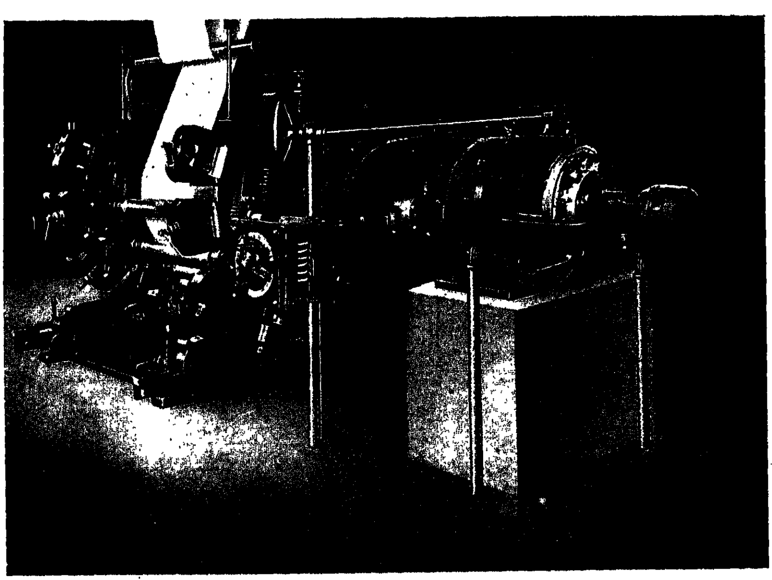


Fig. 1. Eight colour machine with direct connected Asea three-phase commutator motor and self-contained reduction gear.

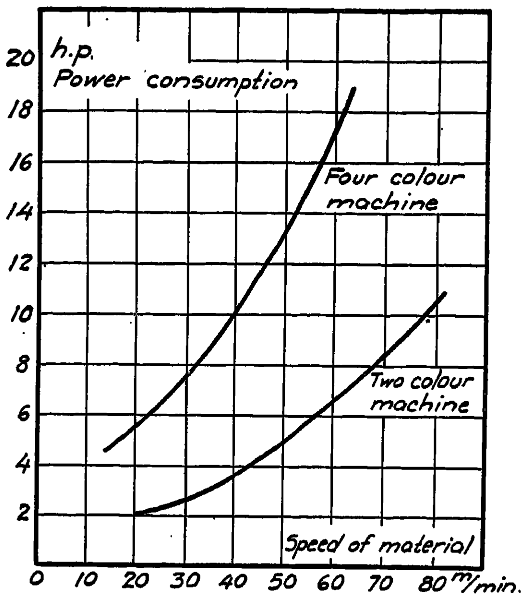


Fig. 2. Power curves for two and four colour machines.

leaves the printing machine or else is passed over specially heated boxes. The colours are then made permanent according to their different nature, after which the cloth undergoes a final finishing process.

For the driving equipment of roller printing machines the first necessity is the possibility of obtaining definite speed regulation over a wide range which not only includes the normal running speeds determined by the quality of the material, but also the considerably lower speeds which are required for registering the rollers before starting printing, and for checking and controlling the progress of the work. The step by step alteration of speed which is obtained when running from a line shaft with stepped pulleys fulfils the requirements very incompletely, although the method is often used on account of the difficulties generally believed to exist in obtaining a suitable motor for direct drive. The machine which suggests itself is the DC motor, but apart from the fact that in most cases DC is not available for driving the motor, these machines cannot in general be used on a variable speed without special design. The known qualities of speed regulation of DC motors, by varying the field current, can often only be obtained by making use of special regulating units, or by the installation in the factory of a number of multi-wire DC systems with their own generators, which in spite of their high installation cost, have nevertheless been very largely used in a number of countries, showing unquestionably that there must be great advantages in the possibility of a large amount of speed regulation. A common induction motor cannot be considered, as this only permits speed variation by introducing a resistance into the rotor circuit, and this regulation besides being exceedingly uneconomical, since the speed regulation is obtained by a large increase in losses due to the heating in the resistance, also gives the motor a series characteristic, *i. e.* the speed varies with the load.

For more than ten years Asea has been building three-phase commutator motors of a construction covered by patents, which is exceedingly suitable for the drives in question. It permits of a continuous regulation practically without losses down to at least a third of the normal speed, simply by moving two sets of brushes in relation to one another by means of a toothed sector arrangement. Provided with a special regulating resistance this motor can also give the special low speeds necessary for registering etc.

No special starting arrangements beyond the primary circuit breaker (motor switch case), are required, and the motor when starting develops a torque considerably in excess of the normal, permitting the printing machine to be easily started.

The motor has further a shunt characteristic, and the speed for each position of the brushes in nearly independent of the load, in contrast to that of the ordinary induction motor with rotor regulation and the series commutator motor.

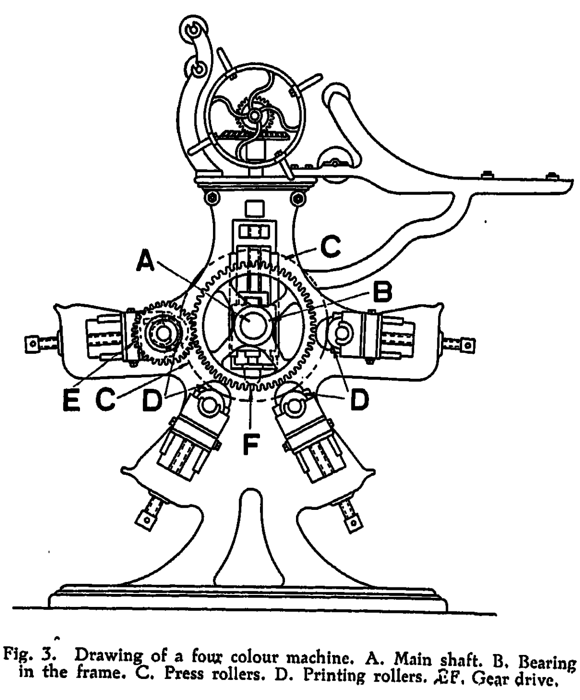


Fig. 3. Drawing of a four colour machine. A. Main shaft. B. Bearing in the frame. C. Press rollers. D. Printing rollers. EF. Gear drive.

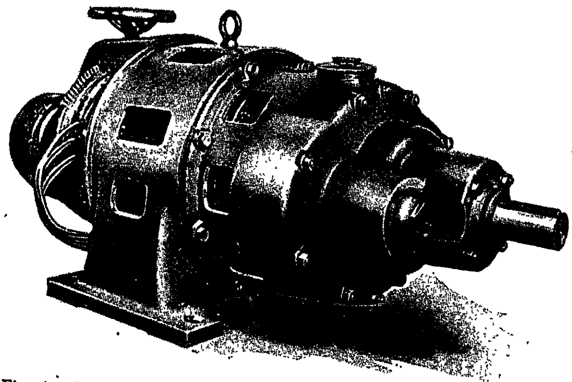


Fig. 4. Asea three-phase commutator motor with self-contained double reduction gear.

For a further description of the motor the reader is referred to an earlier article in the Asea-Journal and the following article in this number.

The power required by a roller printing machine varies, apart from the difference due to the construction of the printing machine itself, according to the material in use, to the number of printing rolls, the speed at which the material is run, and, to a lesser extent, the width of the material, and the quality. For different qualities different pressures are used on the rolls; the pressure should not be greater than necessary as the power taken during start depends to a great extent on this. A satisfactory pressure is almost entirely dependent upon the experience and craftmanship of the printer. As the power required is thus determined by a number of variable factors it is impossible to give any exact figures. The approximate requirement of power under normal conditions is in accordance with the following table, in which the highest and lowest values are taken from a paper (Guildford. Textile Printing Journal A.I.E.E. 1922), the mean values being from determinations made on plants equipped by Asea. With these values a cloth speed of about 80 metres per minute for a one to two colour machine, down to 40 metres per minute for the highest number of colour rolls is given by the table:

No. of colour rolls	Maximum speed of printing	Suitable motor output, h.p.
1—2	80—70	6—9—12
3	70	10—15—20
4	60	12—18—24
6	50	15—24—35
8	50—40	20—30/35—

With increasing speed the power required increases much more rapidly than the printing speed, as shown by the curves in figure 2.

The printing machine requires, as we have already said, a wide range of speed regulation within its normal working range. The highest speed of the material which can be used is chiefly dependent on the speed at which the drying can be continuously carried out after printing; with a thick colour absorbing material accordingly the speed is low, while for thin material a considerably increased speed can be allowed. For the speed variations depending on the quality of the material referred to above, a speed variation in the ratio of 1:3 is most suitable, *i.e.* for example a four colour machine, which is run at a highest speed of 60 metres per minute, may, for a different material, be required to run at as low a speed as 20 metres per minute. In addition to this regulation a further reduction in speed is required for registering the rollers etc., for short periods in the ratio of 1:2 or 1:3, or in other words the lowest speed is about one-seventh or one-ninth of the maximum printing speed, or 5 to 13 metres per minute. For this it is clear that a machine with a large number of rollers printing a complicated pattern requires for careful registration, without wasting too much material, a considerably lower speed than when printing a simple pattern on a one or two colour machine.

The driving shaft of the printing machine (fig. 3), *i.e.* the shaft from which the drums are driven by means of gearing, has in general a speed at the highest rate of printing between 100 and 25 r.p.m., the higher speed for a few colours and the lower for a large number of colours. For connecting the driving motor to the printing machine the best method is by direct coupling to this driving shaft, but as the motor, both from the point of view of price and design, cannot be built for such a low speed as those given above, it is fitted

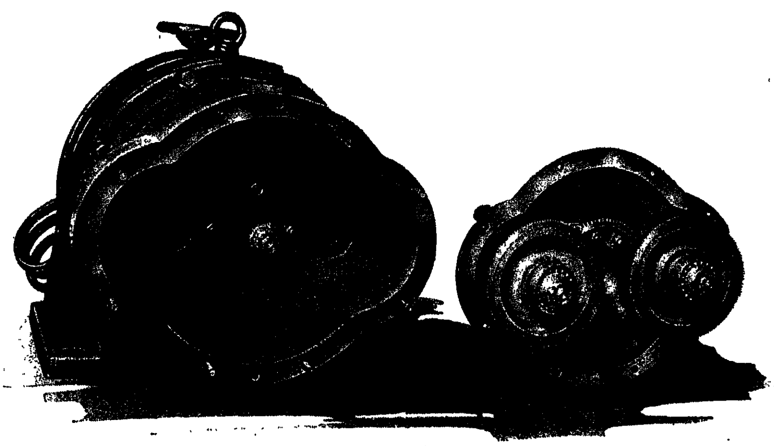


Fig. 5. Reduction gear dismantled.

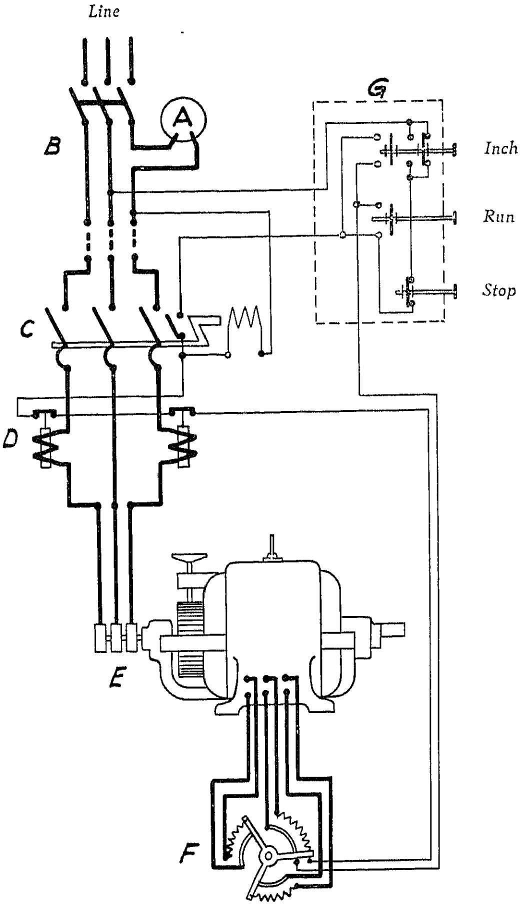


Fig. 6. Connection diagram for a push button operated equipment for a cotton printing machine.

with a self-contained double reduction gear with a ratio between 1:15 and 1:40, depending on the speed of the driven shaft and that of the motor (figs. 4 and 5). These gears, which are furnished by Asea with wheels of special steel and of fine pitch, run in oil, and their efficiency is particularly high (98 to 99 %). If the driving axle of the printing machine can be furnished with an outer bearing and the connection effected through an elastic coupling, such an arrangement is to be preferred from all points of view. If this cannot be done on account of small available space or other reasons, the motor is furnished with an extended gear shaft for carrying the pinion of the gear driving the colour rollers, and this shaft extension is carried at its further end in a bearing in the frame of the printing machine. This arrangement does not however permit a careful adjustment of the bearing referred to.

On six and eight colour machines the above main shaft is often driven by gearing from a second driving shaft having a running speed between 200 and 100 r.p.m. This arrangement is also adopted in all cases on machines having a still larger number of rollers. This driving shaft can be retained and the gear of the motor provided with correspondingly lower gear ratio than it could be with a single reduction gear. By this means a cheaper arrangement is attained, although some drawbacks are introduced, particularly that due to the necessity for placing the motor at a greater height above the ground level, since the second shaft lies above the main shaft. As regards the connection of the motor to the driving shaft the arrangements are the same as have been dealt with above. Chain drive, which is often suggested, is in general less suitable.

Under all conditions the motor is erected upon a suitable base which may be of concrete. As it is relatively high, and as very careful erection is necessary with direct coupling with an extended driving shaft, the provision of this base should be very carefully done, and the permissible loading on the foundations should not be exceeded, on account of the risk of settling and consequent undue stresses in the shaft and bearings.

The equipment of apparatus can be made more or less complete, from a simple motor switch case, to a push button operated automatic equipment arranged for convenient operation. The automatic equipment enables the printer to pay more attention to the actual printing, and when a complicated pattern is to be undertaken this is of considerable advantage. For small machines for one and two colours an equipment consisting of a standard switch case with no-voltage release and ammeter is quite sufficient. The ammeter provides a good check for various operations, among others making it possible to arrange the same pressure on the rollers for a given material. In series with the no-voltage release can be placed one or more push buttons for bringing the machine to a standstill from a distance. The brush shifting arrangement is

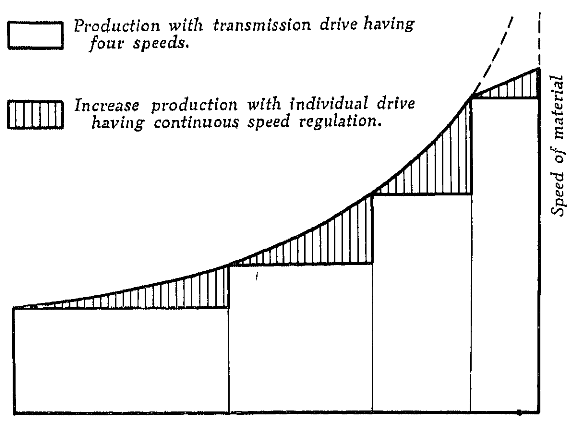


Fig. 7. Production diagram.

provided with a bevel gear and extended shaft with a handwheel or some such arrangement, so that the regulation can be done without it being necessary for the printer to leave his place in front of the rollers. If a series resistance is provided this is erected like the switch case in a convenient and accessible position for the printer.

The arrangement already described is entirely satisfactory from the point of view of safety in operation, but if a more convenient control arrangement is desired, this can be obtained by a push button system, arranged in general in accordance with the connection diagram, figure 6. A push button board is mounted in a suitable place on the frame of the printing machine, and the printer is able to start and stop the motor simply by pressing the button controlling the automatic switch. For starting the machine at the beginning of printing it is only necessary to see that both the brushes and the series resistance, if one is provided, are in their low speed position. On pressing the push button "Inch" the motor starts at its lowest speed, and continues so to run as long as the button is pressed down. On pressing the push button "Run" the motor continues to run, even after the push button is released, until it is stopped by depressing the "Stop" button. Several of these control boards can be placed in convenient positions. As soon as registering is completed the motor is accelerated to a suitable speed by turning the handwheel operating the brush gear after first short circuiting the series resistance when one is provided. For control during the progress of the work the speed can be reduced to the lowest value by operating the above handwheel, and an immediate stop is obtained by pressing down the "Stop" button.

Automatic regulation can be further developed by providing the brush shifting gear with an operating motor so that the control can be entirely carried out by means of push buttons. This arrangement can only be justified on exceedingly large machines.

Individual drive of drum printing machines by variable speed commutator motors introduces considerable advantages in comparison with drive from line shafting, and as regards regulation and efficiency is quite as good as DC drive, while it is much better than DC from the point of view of the simplicity of the installation. In comparison with drive from shafting with a few different speeds, the individual drive permits a very considerable increase in production, on account of the possibility of continuous speed regulation and the consequent use of the most suitable speed at all times.

The diagram figure 7 shows that this may amount to about 16 % when changing over from a transmission drive with four speeds having a total ratio of 1:3, which makes it necessary to divide the production in a similar manner in accordance with the four definite speeds which lie in a geometric series. The maximun speed with individual drive for the quality of material which before could be run at a higher speed than the highest which the transmission drive allowed, has only been supposed increased by 10 %, while the highest speeds on the remaining steps with transmission drive are assumed to be unchanged. These assumptions are actually exceeded, on account of the smooth running which is obtained with a direct coupled motor. On taking account of this condition and of the time saving which is obtained through the simplicity of regulation the increased production due to the individual drive may be reckoned to reach 20 %. The cost of the electrical equipment is met by the increased production in an exceedingly short time if the increase is of the above value, so that the problem introduced by the individual drive of rotary textile printing machines may be said to have been solved in a particularly satisfactory manner, both from the economical and technical standpoints by Asea three-phase commutator motors with self-contained reduction gears.

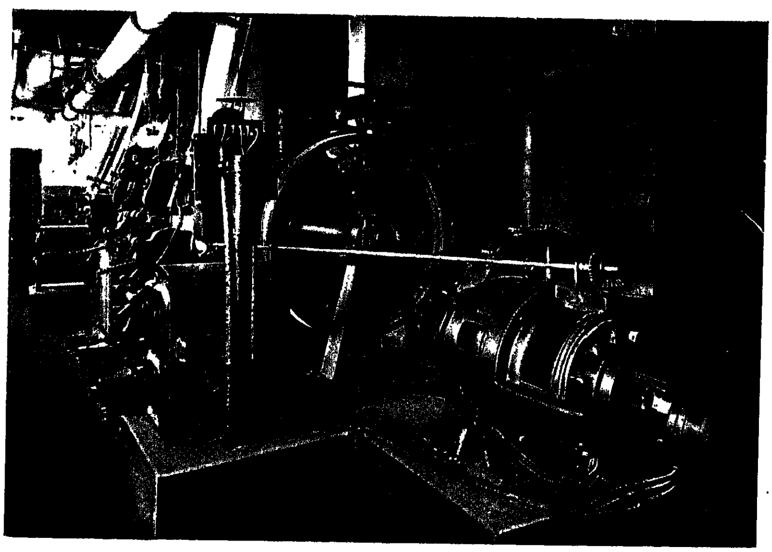


Fig. 8. Three roller printing machines with direct connected Asea three-phase commutator motors.

ALTERNATING CURRENT MOTORS WITH CONTINUOUS SPEED REGULATION.

This article deals only with motors where continuous speed regulation is possible, theoretically as well as practically; *i.e.* where even a very small movement of the regulating mechanism gives a correspondingly small alteration in the speed. Consequently, motors with step-by-step regulation will not be discussed, but only AC commutator motors where the speed regulation is achieved by means of brush rotation.

Regarding the *single* phase commutator motors, only the *repulsion* motors are capable of speed variation within wide limits. The repulsion motor in its simplest form has a stator fractionally wound and a rotor similar to that of an ordinary DC machine. Only the stator is supplied with energy and the brushes are shortcircuited. If the brushes are placed in such a position that the rotor winding becomes co-axial with the stator winding, the motor acts like a shortcircuited transformer, and when the voltage is applied, it causes a heavy current in both stator and rotor windings. However, the motor has no torque as it has no magnetic field that can produce a torque together with the current carrying conductors. If the brushes are rotated 90 electr. degrees in either direction no current is induced in the rotor conductors and the motor still has no torque. The current consumed by the stator winding is only equal to the necessary magnetizing current. With intermediate brush positions the rotor current will not be excessive and the position of the rotor conductors in the stator field is such as to develop a torque which is adjustable from zero to a certain maximum by merely rotating the brushes.

A closer investigation of the qualities of the repulsion motor not being the object of this article, it is only mentioned here that the speed is conveniently adjusted by brush shifting from standstill up to a certain limit; further, the motor has series characteristics, *i.e.* the speed becomes very high on light loads. Hence, it will be understood that the repulsion motor is not generally suitable for industrial use where the speed must not vary very much from full load to no load. In some instances, when driving certain printing presses or ring spinning frames, the load is very constant, and there the single-phase repulsion motor may be used to advantage. However, it should be observed that this motor is rather sensitive to variations of the line voltage, to such an extent that the speed varies a little more than the voltage. At low speeds these variations may be excessive.

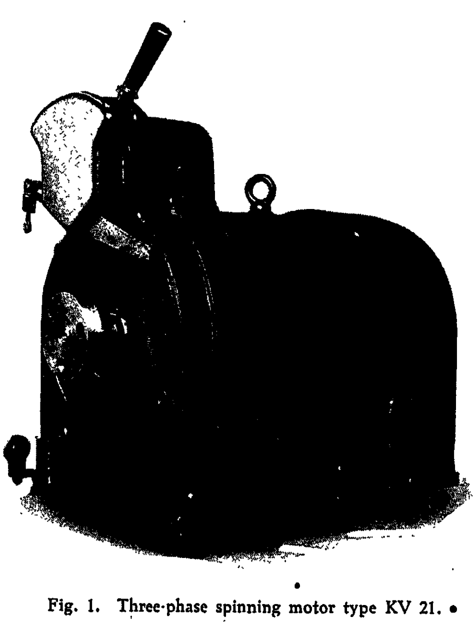


Fig. 1. Three-phase spinning motor type KV 21.

The repulsion motor gives the best service at approximately synchronism as at this speed the commutation is facilitated to a certain extent by the existence of the rotating field. At higher speeds the commutating conditions rapidly grow unfavourable and repulsion motors should not be used at oversynchronous speeds unless they are very liberally dimensioned.

An adjustable speed *three-phase commutator* motor can be designed either as a series motor or as a shunt motor.

The *three-phase series* motor consists of an ordinary three-phase wound stator and a DC armature with a three-phase brush gear, each stator phase being connected in series with its corresponding set of brushes. Provided that the number of conductors in the rotor is suited to that of the stator, the motor thus composed, acts in much the same way as the repulsion motor. It has series characteristics and the speed is adjustable by brush rotation only. Moreover the commutation is at its best at synchronous speed and the commutating difficulties increase with the speed, although not nearly so quickly as with the single-phase motor.

Since the rotor has to be wound for a comparatively low voltage — much less than that corresponding to standard distribution voltages — it is necessary to feed it through a transformer. By suitably designing this transformer, it is possible to change the characteristics of the motor from that of a series motor to something like that of a compound motor. This is achieved simply by saturating the core of the transformer, as the rotor voltage, being zero at synchronism, tends to increase when the speed increases. The more the speed increases the more the transformer becomes saturated and the greater the phase

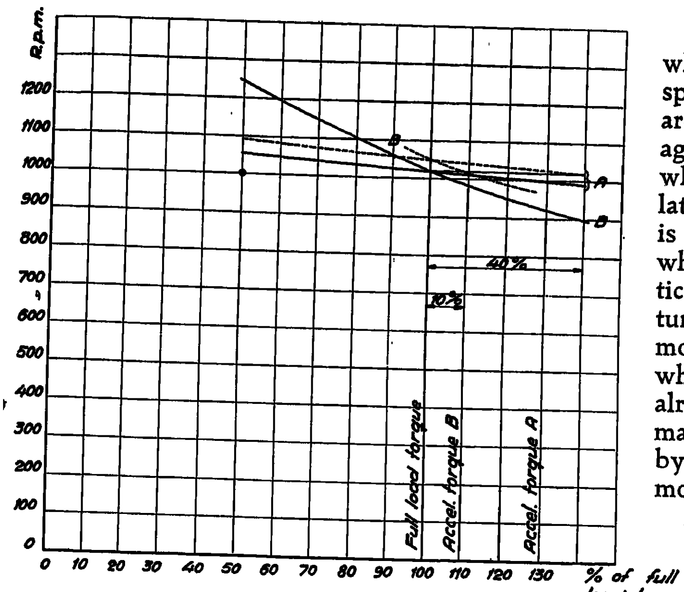


Fig. 2.

displacement between the stator and the rotor current, with the result that the rotor torque steadily decreases. At a certain speed the motor cannot produce more torque than that necessary to cover its own losses, which means that it has gained a comparatively stable no-load speed. However, at speeds below synchronism it is not unlike a series motor.

The *three-phase shunt motor* is, without doubt, the most adaptable motor for different purposes. This motor, developed by Asea and put on the market since 1914 in its variety of sizes, has been shortly described in a previous issue of the Asea-Journal. A general description of the more outstanding features of the motor with some of its applications may therefore be more adequate.

The motor can be switched in on full voltage with the brushes in the "start" position, and is capable of starting against nearly twice full load torque without the line current exceeding the normal by more than 30—50 %. The speed is adjustable from 50 % below synchronism to about 50 % above the same speed by brush rotation only, the motor thus being capable of speed variation within wide limits. The speed decreases a little from no-load to full load, and the speed drop, counted in revolutions per minute, is about the same at all brush positions. As regards the commutation, Asea's three-phase commutator motor is superior to those mentioned above, since it works equally well at all speeds. Variations of the line voltage affect the motor in the same way as an ordinary induction motor, *i.e.* the speed drop increases a little when the voltage is lowered and decreases when the voltage is raised.

At present there are a great many industries which require motors capable of an economical speed variation within wide limits and which are practically independent of fluctations in voltage and load. In all such cases, as for example, where motors for paper making machines, wheel lathes, are to be considered, the series motor is at a disadvantage. Only in such instances where the torque of the driven machine is practically constant has the series motor an opportunity of competing successfully with the shunt motor. A ring spinning machine is an example where the series motor *may* be used and has already been used with varying success, and it may be of interest to see what can be gained by the use of shunt motors instead of series motors for this special drive.

In order to get the highest possible production together with the best quality of yarn, it is essential that the frame be driven at a speed variable to such an extent as to keep the tension of the thread constant. Thus the speed should be at a minimum when the yarn is spun on a point of the cop where the diameter is small and greater when the thread is moved away from the centre of the cop. This means partly that the speed of the motor must vary periodically with the movements of the ring rail, and partly that the average speed must be kept low when spinning the bottom of the cop. Theoretically, the series motor can handle such a regulation equally as well as the shunt motor.

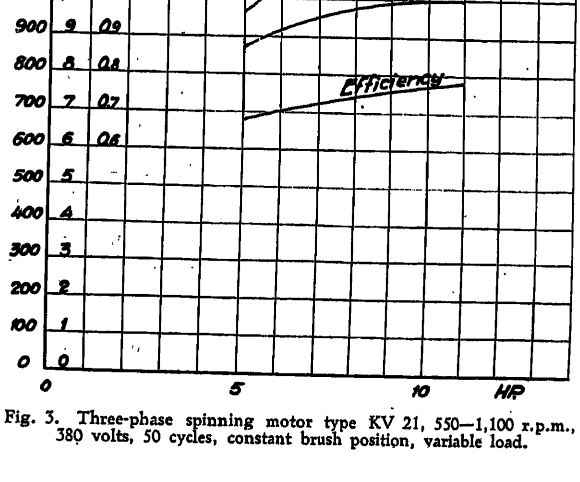


Fig. 3. Three-phase spinning motor type KV 21, 550—1,100 r.p.m., 380 volts, 50 cycles, constant brush position, variable load.

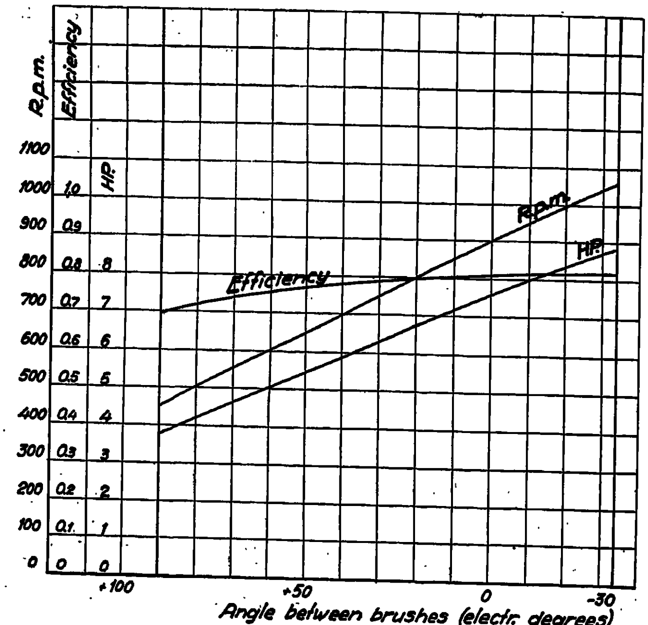


Fig. 4. Three-phase spinning motor type KV 21. Variable brush position. Constant torque corresponding to 8.5 h.p. at 1,000 r.p.m.

Practically, there is a difference, and this difference is due to the fact that with the shunt motor the speed follows the movements of the regulating mechanism much more closely than is the case with the series motor. Fig. 2 will explain this point more clearly. Two of the four curves plotted (A) refer to Asea's shunt motor and the other two (B) to a series motor. The two brush positions are so chosen that the speeds for 100 % torque are 1,050 and 1,020 r.p.m. respectively for either motor. The decrease in speed corresponding to an increase in torque of 10 %, is 3 % for the series motor and only 0.7 % for the shunt motor. If the speed of the series motor is to be increased by 3 % to 1,050 r.p.m. and the brushes are momentarily shifted to the required position, the torque increases momentarily to 110 %, *i.e.* 10 % is left for accelerating the masses. The shunt motor gives 140 % torque for the corresponding brush rotation, *i.e.* 40 % of the torque for acceleration, which is four times as much as the series motor can develop. Hence the superiority of the shunt motor is obvious, especially when it comes to the periodic variation, where the rotating masses have to be accelerated and retarded. In the case of a series motor it is necessary to let the regulating mechanism have a much greater working range than would be the case with the shunt motor. Due to the shunt characteristic of this motor, the extra torque required to overcome cold bearing friction, which occurs when the frame has been standing, will not cause any appreciable drop in speed. The inherent speed reduction of the series motor under these conditions would reduce the output of the spinning frame, which seems to have actually occurred (see "The Electrician" 1921, Feb. 4) where the series motors installed had to be replaced by induction motors supplied with varying frequency. The shunt commutator motor now offers a much simpler solution of this problem.

The influence of fluctuations in the voltage is of great importance. How the shunt motor compares with the series motor in this respect is clearly shown by the fact that 10 % variation in voltage causes at least 8 % variation in speed for the series motor, the corresponding figure being 2 % for the shunt motor. A great many of the thread breakages which occur in spinning factories where series motors are employed can be put to the account of the varying voltage, especially if the spinning frame works at a high yarn tension.

In order to make the regulation automatic, a mechanical device is used which is directly driven from the spinning frame and coupled to the regulating handle of the motor. The speed variation is obtained by means of suitably shaped cams, one for the periodic variation and the other for regulating the fundamental speed.

Single-phase commutator motors have been supplied by Asea for a long period of time. Experience from several factories has plainly shown that by adopting the variable speed drive the quality of the yarn has improved and the output increased. However, the automatic regulator has, in some instances, not given full satisfaction owing to the great amount of work it had to do, the reason of which has been previously explained. Asea has, therefore, in order to overcome the difficulties, developed the ring spinning shunt motor, and the reports of the new motor's performance are most encouraging and give us good cause to believe that this motor can fulfill the desired conditions better than any other equipment.

Vesteras 1925. Vestmanlands Allehanda Printing Co.

ASEA-JOURNAL

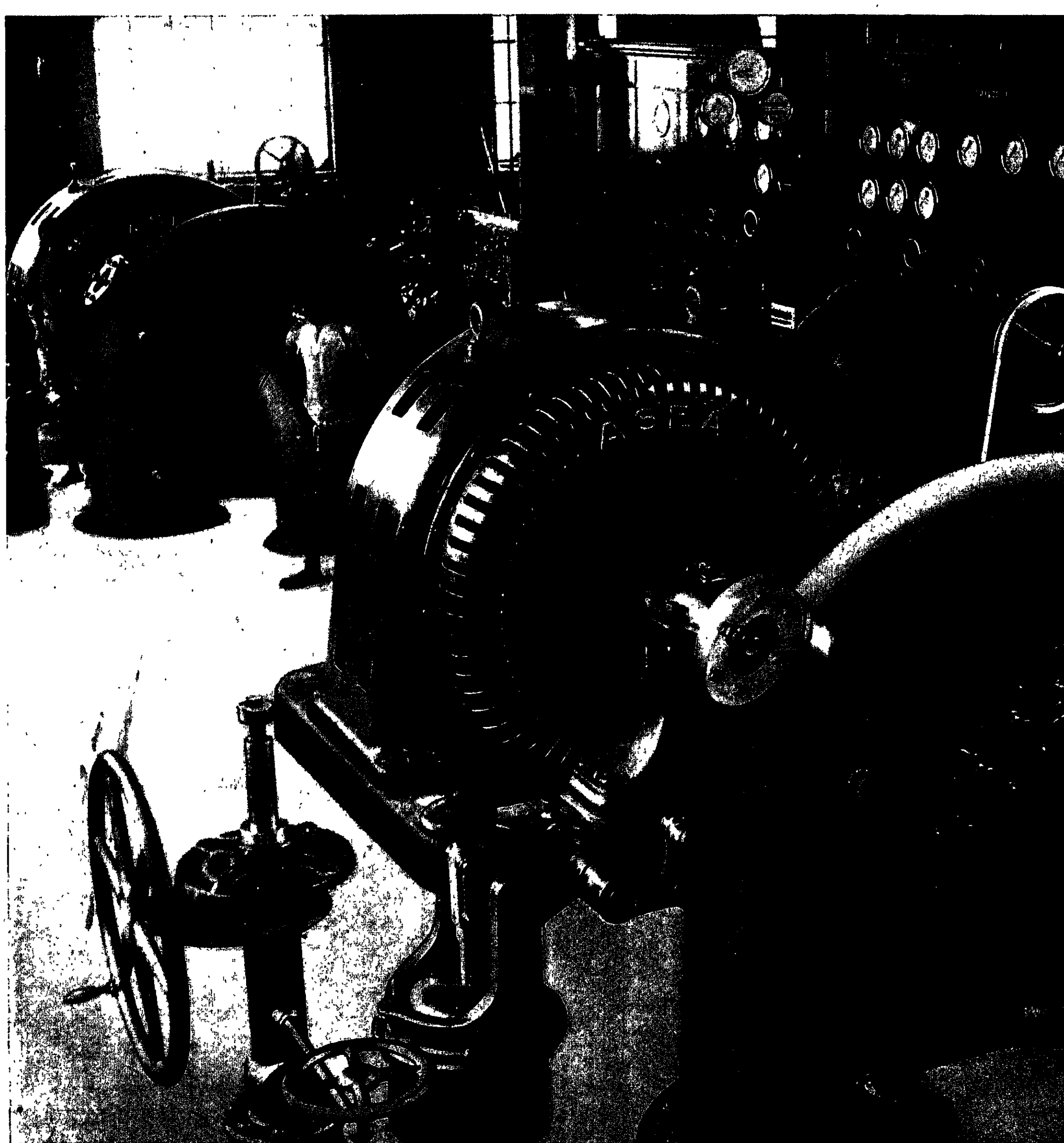
ALLMÄNNA SVENSKA
ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

VOL. II
1925

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesterås, Sweden.
Permission is given to reprint articles or extracts from this journal,
on condition that the name — Asea-Journal — is clearly stated.

MAY
No. 5



Power station of the Société de Ciments du Katanga, Belgian Congo. 2,200 kVA in Asea generators.

ASEA IN THE BELGIAN CONGO.

Fig. 1. Ox and mule transport of machinery.

Asea in 1923—1924 supplied and erected a complete power plant of medium size for the Société de Ciments du Katanga, a Belgian cement company in the southern Congo. As this is the first installation of its kind in that part of the world some particulars may be of interest to our readers.

The province of Katanga, a district rich in ore, at the source of the River Congo, has been colonised to a great extent since the war by the Belgians, who have commenced the construction of mines and have built railways for the transport of ore etc. It had been necessary to obtain the cement required for these works from Rhodesia, which lies about 1,000 miles to the south, and this great distance made the price extremely unfavourable (in 1923 the price per ton was £ 3. 10. 0. at the border of Rhodesia), and it was accordingly found to be necessary to start a cement factory in the district. At Lubudi, where the railway from Rhodesia crosses one of the tributaries of the Congo, there exists an unlimited quantity of material for making cement, a small coal mine at Luéna, about 75 miles to the north supplies the necessary coal, and from a waterfall 8 miles to the west of the railway sufficient power for the work is supplied.

Fig. 2. Temporary slipway for lowering material to the power station (seen on the left).

This waterfall, now known as the Kalule Chutes, has a fall of about 90 metres, and it is estimated that it can supply continuously the whole year round a maxi-

mum of 4,000 h.p. After the heavy rains which occur in January the river rises, and usually during March about five to six times this amount of power is available and this fact greatly increased the difficulties of carrying out the civil engineering side of the work.

Fig. 3. Sleeping quarters.

The cement mill requires when in full operation about 1,500 h.p. which corresponds to a production of 160 tons of cement per day. In order to make certain of the power two generator units where installed, self-ventilating, and each of 1,100 kVA, 750 r.p.m., 50 cycles, 3,000 volts, power factor 0.75, three-phase, of which accordingly one is a stand-by.

The generators, of which each is coupled to a Francis turbine, have at full load an efficiency of 93.5 %, and are excited by direct coupled exciters of 12.5 kW at 110 volts. The rise in voltage on switching off full load at 3,000 volts is 26 %. The voltage is reduced by automatic regulators to its normal value in about 5 seconds.

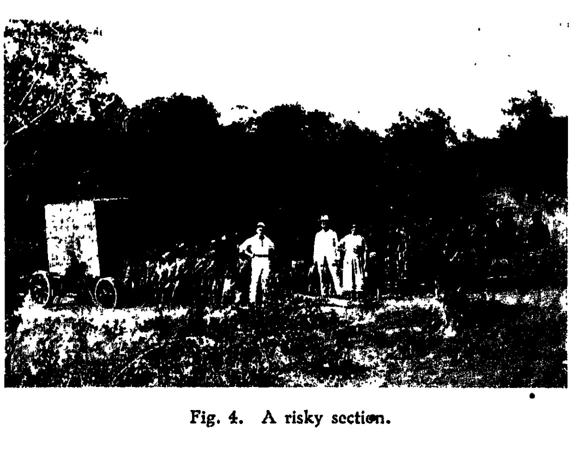


Fig. 4. A risky section.

Fig. 5. Finishing and enamelling the switchboard at the power station.

The power station building, which is situated at the bottom of a ravine 90 metres deep, is of brick and steel construction. It has a machine room with 3,000 volt switchgear on the first floor, 1,500 volt switchgear on the second floor, and lightning and surge protection in a small tower over the 1,500 volt switches. Each generator unit is provided with all the usual instruments; a Tirill voltage regulator is used for the two machines. The generators are connected to two 3,000 volt busbars provided with isolating switches enabling them to be connected together.

Fig. 6. Distribution board and 150 h.p. motor driving ball mill at cement works in Lubudi.

From the busbar system three step-up transformers are supplied, each of 550 kVA, 3,000/15,000 volts star connected and with neutral point brought out on the L. T. side, and extra terminals for ± 5 % on the H.T. winding.

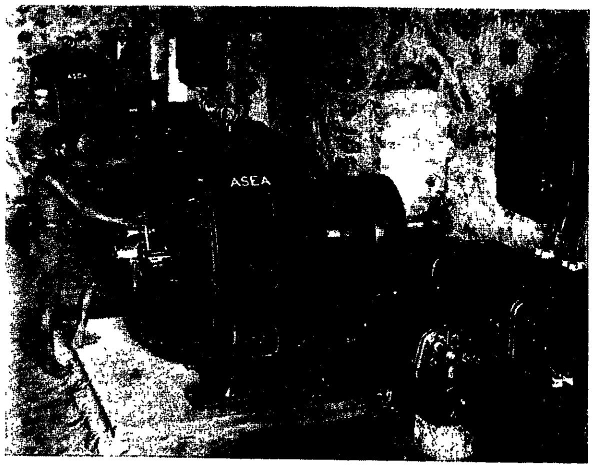


Fig. 7. Cement works at Lubudi, 150 h.p. motor with switch case and starter.

Fig. 8. Rotary kiln with 48 h.p. motor in cement works at Lubudi.

All instruments for both 3,000 and 15,000 volts are mounted on a sheet steel switchboard erected against the wall of the machine room. Behind these switchboards all the station relays are mounted so as to be easily accessible for inspection and adjustment. All the oil switches, with the exception of the line circuit breakers, are operated through rods from the machine room.

The overhead line between the station and the cement works is carried on wooden poles, and consists of four 25 mm^2 copper conductors with an upper conductor of 50 mm^2 galvanised iron earthed at every fourth pole. As this line is only temporary, (it will be rebuilt later with reinforced concrete poles), as much use as possible has been made of growing trees along the route. These trees resist the climatic conditions better than trees specially felled for poles. Over long stretches the line is at a very limited height above the ground (3 to 4 metres) as this was considered of small importance owing to the scantiness of the population and comparative absence of large animals. For transporting the heavy machine parts from the upper level to the bottom of the ravine, a simple slipway was constructed with steel rails parallel to the pipe line, at a place where the side of the ravine was comparatively even and at a slope of about 45°. All material was brought from the railway through the surrounding jungle by ox and mule haulage, and in spite of the primitive transport arrangements the whole of the work was carried through and the erection completed without any serious mishap.

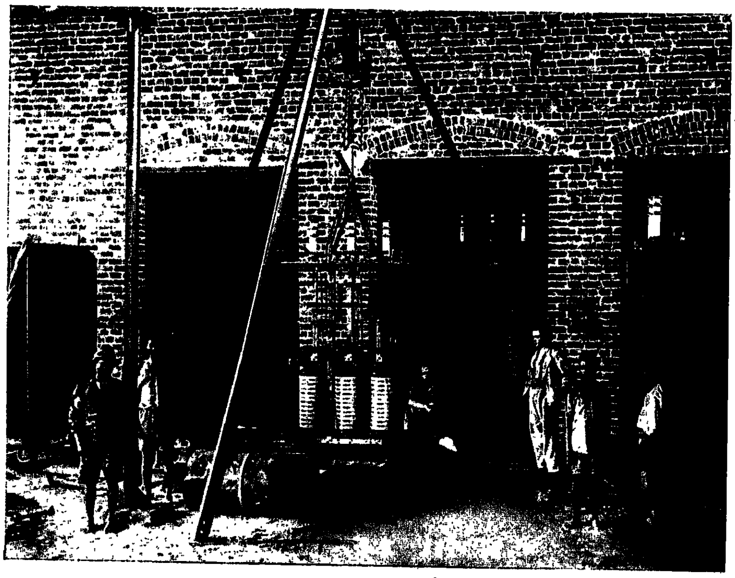


Fig. 9. Erecting step-down transformer at Lubudi.

In the cement mill 8 miles from the power station are three step-down transformers, each of 550 kVA, 15,000/550 volts and otherwise similar to the step-up transformers. These are placed in brick cubicles. The switchgear for these transformers and the main di-

stribution board for the motors at the mill are erected in a substation in the works.

For the cement works about 20 motors were supplied and erected, amounting altogether to about 1,200 h.p.

All these motors are three-phase induction motors, 500 volts, 50 cycles, of standard open type (Form B). They are specially insulated for the tropical climate and provided with dust-tight bearings. For the motors switch cases and starters were also supplied, the former of type SBO and the latter of types PTG, PTSO, PTO and PT.

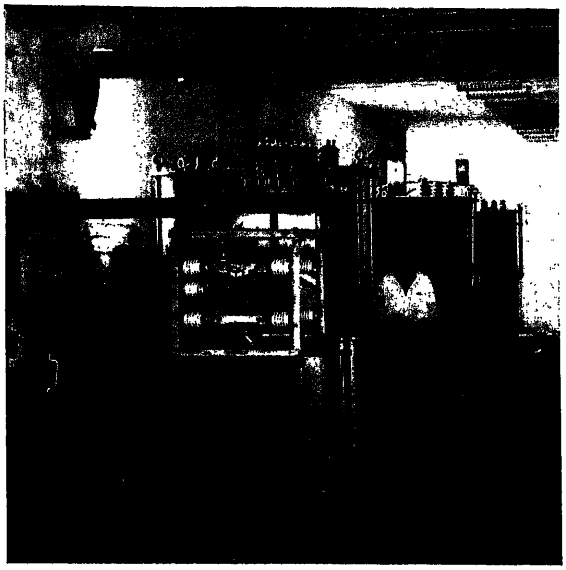


Fig. 10. L'Union Minière du Katanga, Panda. Three furnace transformers of 480 kVA, 6,600/40—50—60 volts, 50 cycles.

The erection of these machines included also the laying and connecting of all underground cables; the motors are connected to a common underground cable network and feeder cables are laid from the main distribution board to the motors lying some distance outside the works buildings.

The plant, which was set to work at the beginning of March 1924, was entirely erected by Asea's staff with the help of native labour. Up to the present date it has operated in a perfectly satisfactory manner, showing that the machines and apparatus supplied by Asea are entirely satisfactory even under the difficult conditions and in the tropical climate.

On account of the warm and damp air in the power station, the insulation resistance of the generators is lower to a certain extent when the generator is out of service for a considerable time, but it never falls below the value allowed by the English Standardisation Rules, and this shows that the construction fully satisfies the conditions in spite of the fact that no special investigation was first carried out regarding temperature and humidity.

For another company, l'Union Minière du Katanga, which owns and operates several copper mines in this district, Asea supplied at the beginning of last year three single-phase oil insulated and water-cooled furnace transformers, type EVO-50, of 480 kVA, 6,600/40—50—60 volts, 50 cycles, with necessary switchgear. These are erected in Panda, a large district lying about 120 miles to the south of the plant at Lubudi described above, and where l'Union Minière has a large concentrating plant for copper ore.

Fig. 11. Camp.

CONSIDERATIONS IN THE PROVISION OF GOOD ARTIFICIAL LIGHTING.

1. *The Physical Properties of Light.*

It is light which enables us to appreciate the shape and colour of the objects which surround us, if we disregard the limited possibilities in this respect derived from the sense of touch. For this purpose we are provided with an optical apparatus, the eye, the function of which is to produce an image of the objects looked at, and to transmit this to the brain by means of the optic nerves. Light, is at the present time considered to be a wave motion in the ether and it is concluded that light waves only differ in their length from other electromagnetic wave motions, Röntgen rays, heat waves, wireless waves, etc.

Light is propagated at a speed of 300,000 kilometres per second in a vacuum, but the speed is not the same in materials such as water or glass. In water the speed is only 225,000 kilometres per second.

Light of different colours is propagated with the same speed so that the equation $\nu \cdot \lambda = 300{,}000{,}000$ m is true for light of different colours. Ordinary daylight which the eye appreciates as white (colourless) light, is not of a single colour, monochromatic, but is made up of a number of different colours viz, violet, indigo, blue, green, yellow, orange and red, which, when they affect the eye in correct proportions, are appreciated as white light.

The colour of light is determined by its wave length. The variations in colour for different wavelengths can be compared with the variation in pitch for different lengths of sound waves.

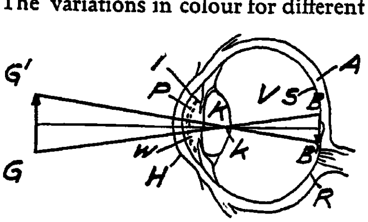


Fig. 1.

When sunlight traverses a glass prism or a simple lens it is broken up and a spectrum is formed. In the visible part of the spectrum the red rays have the greatest wave length and are least refracted, so that they are found at one end of the visible spectrum. The violet rays have the shortest wave length and are most refracted, they are accordingly found at the other extremity of the visible spectrum.

The length of the longest waves constituting red light is 0.00075 mm, and the length of the shortest rays constituting violet light is 0.00038 mm. Beyond these limits, however, there exist in visible rays of other wave lengths. Those lying immediately beyond the red part of the spectrum, the so-called infra-red, are appreciated by us as heat rays. In this part of the spectrum waves have been measured up to a wave length of 0.1 mm and far beyond these we meet with wireless waves, whose length can be reckoned within the limits of one and several thousand metres. The invisible and so-called ultraviolet rays have a wave length of 0.00029, and have been called chemical rays since they exercise a strong chemical effect upon certain preparations (photographic plates, sensitised paper, etc.). Still further to the right of the spectrum the curious Röntgen rays are found, which have a wave length of 0.0000001 mm.

2. *The Structure of the Eye.*

Since the eye is the instrument which the brain possesses for visualising the different properties of colours which are looked at, it is necessary to know something of its structure in order to study the various problems in lighting.

The eye can be most simply regarded as a camera obscura. The dioptric apparatus of the eye, fig. 1, consists of the cornea H, the aqueous humour W, the iris I, the lens K, the membrane V, and the retina R.

When light enters the eye it traverses several media with various refractive indices and falls on the retina where a greatly reduced inverted image of the object regarded is formed (fig. 1).

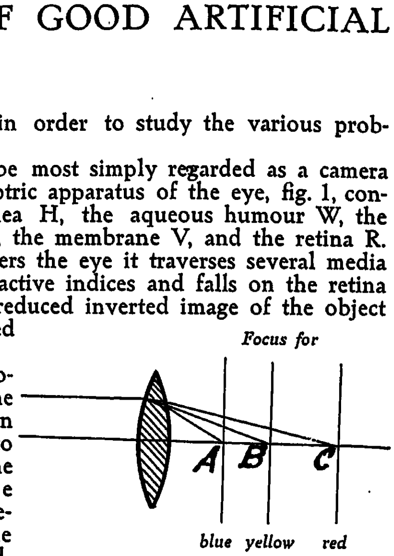


Fig. 2.

In a simple photographic lens the light is resolved in the same way into a picture, but the different wave lengths are not refracted to the same extent and accordingly meet the axis of the lens at different points, compare fig. 2.

As the screen upon which the picture is formed cannot be placed at more than one point, for example at (A) the edges of the picture become blurred and coloured by yellow and red rays. This phenomenon is known as chromatic aberration, and can be overcome to some extent by using several lenses manufactured from glass having different refractive indices and combined together into a compound lens. We then obtain what is known as an achromatic lens system. The spherical aberration of such a lens consists of the rays which traverse it in the neighbourhood of its edges and are not refracted to the same extent as those which traverse it in the neighbourhood of its axis, fig. 3. This characteristic can be overcome suitably by limiting the radius of curvature of the lens surface and by combining several lenses into a system which is then known as aplanatic.

The eye is both achromatic and aplanatic, and as we have seen before, the light rays in this case pass through bodies having different refractive indices combined together into a single system.

We can imagine the dioptric system in the eye as represented by a simple convex lens which, as we know, refracts parallel rays in such a way that they come to a focus at a point behind the lens known as the principal focus. On the assumption that the angle of vision is sufficiently great, the eye can picture an object at a great distance. The principal focus of the eye coincides with the position of the retina. But as it is possible to see objects lying nearer the eye, the rays from which are divergent when they reach the eye and still form an image on the retina, while the refractive power of the eye remains unchanged, it follows that the eye possesses the ability of altering its own refractive power within the range of vision to suit the distance at which the object happens to be. The lens of the eye also is able to alter its own form by the exertion of the ciliary muscles, and by this means the position of its principal focus, so as to adapt itself to varying distances, this being known as the accommodation of the eye. Further, the eye is able to regulate the amount

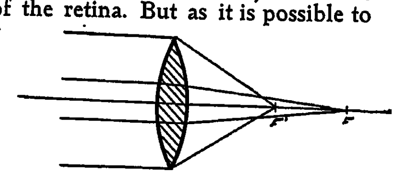


Fig. 3.

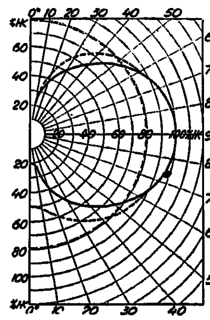


Fig. 4.

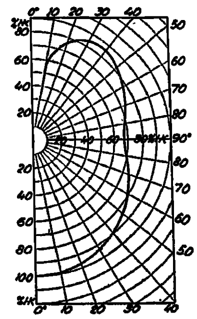


Fig. 5.

of light which enters it by means of the iris, so that this amount is kept as constant as possible. The regulation of light which is permitted in this way is considerable. As an example it may be stated that the eye, without great difficulty, can adapt itself for an illumination of 150,000 lux, which may be expected on a cloudless summer day when the sun is in the zenith, and also equally well for an illumination of 400 lux which may be expected when the sun is in the neighbourhood of the horizon. The cloudless summer sky has an illumination of 0.4 lux.

The sensitivity of the eye to colours is not yet fully understood but appears to depend upon the fact that different "rods and cones" on the retina are affected by different colours, and which, when they are acted upon by the colours in the correct proportion which go to make up daylight, produce the sensation of white light.

3. *Vision.*

A necessity for vision is that the objects regarded should be thrown in sharp focus upon the retina of the eye. In order to attain this, the eye endeavours to accommodate itself, and to regulate the light entering until this definite image is obtained.

The regulation of the eye is not obtained without effort, particularly when it has to be done rapidly, so that sources of illumination which have a continuously varying strength, making it necessary for the regulating apparatus of the eye to be continually in operation, are particularly tiring, both to the eye and to the brain. For weak light, even if this is particularly constant, the eye may also be damaged, since it is continuosly subjected to overstrain.

If the eye is subjected to strong light, as for example by looking at the sun, at an electric arc, or at certain gas flames used in connection with welding, the eye will also be injured. This is particularly the case if the source of illumination is rich in ultra-violet rays, as is the case with the electric arc, the quartz lamp etc.

To enable the eye to focus an image upon the retina, which can be received by the brain without undue strain, it is necessary that the illumination of the object in question is suitable to the requirements of the eye.

LANGLEY discovered that a definite amount of light energy was required in order to obtain a visible image upon the retina. With green light 10^{-8} ergs are required in order to obtain suitable sensation, on the assumption that the energy is furnished in 0.5 seconds. With the deepest red light 10^{-3} ergs are required during the same time. If this is expressed in watt hours, then $27.8 \cdot 10^{-20}$ Wh are required for green light, and $27.8 \cdot 10^{-15}$ Wh for red light. He also stated the sensitivity of the eye to different varieties of light in comparisön with one another, table 1.

Vision also depends upon the colour of light and upon certain contrasts in the illumination. Illumination should be evenly distributed but not so much diffused as to furnish an unsatisfactory amount of relief, making the objects give a flat impression. This may be exemplified by a photograph taken of an object in diffused light, the result being quite flat, whereas in order to be satisfactory the contours should come out boldly.

We must remember that we are able to see illuminated objects owing to their ability to reflect light. In order that an object which is only of one colour may be clearly visible, it is necessary that there should be a certain contrast in the reflected light.

Diffused light should accordingly not be entirely wanting in direct rays.

Table 1.

Colour	Dark Red	Red	Orange	Yellow	Green	Blue	Violet
Wave length	75·	65·	60·	58·	53·	47·	$40 \cdot 10^{-5}$
Relative sensitivity	1	1,200	14,000	28,000	100,000	62,000	1,600

4. *Photometric Units.*

In Scandinavian contries, and also in Germany, Holland, Switzerland and some other places, the Hefner lamp is used as the unit of light and is known as the Hefner unit. The construction of the lamp is determined according to a definite specification. It must have a wick 8 mm in diameter, and must burn with a flame 40 mm in height in air free of carbon dioxide with a certain dryness and barometric pressure. The candle power in the horizontal direction is that of a Hefner unit, or what is usually known in Sweden as a normal candle power. In England, France and America the so-called standard candle (the decimal candle) is used, which is somewhat greater.

1 standard candle power = 1.11 Hefner unit.

For a given lamp the strength of light in a given direction is the same at different distances from the lamp, and is measured by the number of Hefner units which will give the same illumination at the same distance. The illumination at different distances from the lamp accordingly varies.

In order to compare sources of illumination a special measuring instrument known as a photometer is used, see section 11.

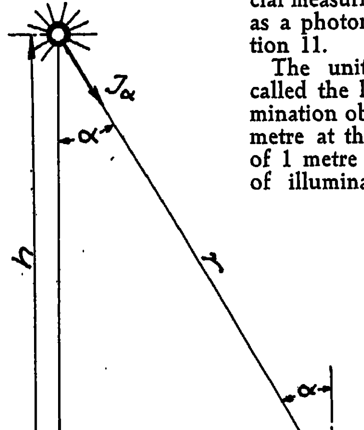


Fig. 6.

The unit of illumination is called the lux. A lux is the illumination obtained on each square metre at the surface of a sphere of 1 metre radius with a source of illumination at the centre equal to one normal candle.

The quantity of light, stream of light, or light flux, which proceeds from a source of illumination within a given solid angle is measured in lumens. From a point source of light of one normal candle there proceeds in all directions accordingly 4π lu-

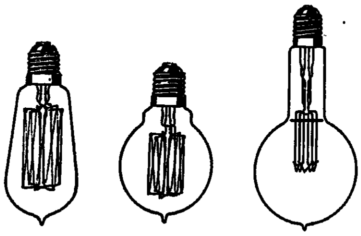


Fig. 7. Fig. 8.

mens. One lumen is the quantity of light proceeding through a unit solid angle from one normal candle. We make use of the following symbols:

I = Strength of light in normal candles.
E_n = Illumination, lux (Lx) = lumen per m².
Φ = Stream of light, lumens (Lm).
A = Area of the illuminated surface in square metres.
a = Area in cm² of the illuminant body.
e = The brightness of the illuminating body in normal candles per cm².
r = Distance between the source of illumination and the illuminated surface, m.
α = Angle between the ray of light and the normal to the illuminated surface.
ω = Solid angle occupied by the outgoing rays of light.

In accordance with LAMBERT's law the general connection between E and I is given by the following equation:

$$E_n = \frac{I}{r^2} \cos \alpha = \frac{d\Phi}{dA} \text{ lux}$$

$$\Phi = I \cdot \omega = \frac{I \cdot A \cdot \cos \alpha}{r^2} = E \cdot A \text{ lumen}$$

$$e = \frac{I}{a} \text{ normal c. p. per cm}^2.$$

Quantity of light = $\Phi \cdot t$ lumen seconds.

To determine the lighting characteristics of a lamp by giving the number of normal candles to which it is equivalent is an inexact method, since, as shown in fig. 4, the strength of the light varies in different directions. The figure shows the distribution of light as a curve in a vertical plane for a lamp hanging vertically. The continuous line shows a metallic filament lamp, and the dotted line a carbon filament lamp.

Fig. 5 shows light distribution curves in the vertical plane for a half-watt lamp hanging vertically. On account of the fact that the strength of light from a lamp varies so much in different directions, as shown by the figures, we speak of horizontal, spherical, and hemispherical mean strength of light.

By a horizontal mean illumination I_h of a source of illumination is meant the mean value of the strength of light in different directions in a horizontal plane through the illuminating body.

By mean spherical strength of light I_o for a source of illumination is meant the strength of a point source of light with even spherical light distribution which gives the same stream of light as the source of illumination in question.

By mean lower hemispherical strength of light I_o for a source of light is meant the strength of a point source of light with even light distribution, which for the lower part of a hemisphere affords the same stream of light as the source of light in question.

The proper method of estimating the illumination characteristics of a lamp is to give the value of the stream of light *i. e.* the number of lumens which proceed from the lamp, compare table 4.

The illumination on a surface is otherwise only dependent on the vertical component of the quantity of light.

In order to determine the illumination on a surface one must accordingly take into consideration the angle at which the light rays meet the surface, so that as regards the strength of the light one works from the light distribution curve of the lamp in its fitting.

Assume that the strength of light in the direction normal to an element of surface ΔX is I_α. The illumination on the element is then:

$$E = \frac{I_\alpha}{r^2} \cdot \cos \alpha \quad \text{but } r^2 = a^2 + h^2$$

$$\text{and } \cos \alpha = \frac{h}{\sqrt{a^2 + h^2}} \therefore E = \frac{I_\alpha \cdot h}{\sqrt{(a^2+h^2)}^{\,3/2}} \quad \text{lux}$$

By estimating the illumination on several surface elements we are enabled to plot horizontal illumination curves. It is also possible to make use of graphical methods which with less trouble lead to results equally good from a practical point of view.

5. *Properties of Sources of Light.*

In the choice of artificial light so many different and disconnected factors must be introduced that we have to attempt to make the result obtained as suitable as possible, having regard to the particular requirements of the lighting installation. The most important factors are that the lighting shall be satisfactory optically, and that running and installation costs must be kept within reasonable limits.

The sources of light at present in use to any great extent in industrial service are the electric light and certain kinds of gas lighting. For electric light, incandescent lamps with carbon and metal filaments, arc lamps, mercury vapour lamps, glow lamps and Moore's vacuum tubes etc. are used. As regards gas lighting coal gas and acetylene are most usual. Of sources of electric light metal filament lamps have by far the greatest field of use, both for industrial work and private house lighting.

Modern lamps are worked in general at a very high temperature, as one in this way is successful in transforming a greater part of the energy into light and the efficiency of the lamp is increased. In this way the colour of the light approaches more towards the violet side of the spectrum, and is richer in rays of short wave length.

The temperature of the incandescent filament in an ordinary metal filament lamp, which requires one watt per candle power, reaches approximately 2,100°C; the lamp has a life of about 2,000 hours, and the efficiency = 5.5 %. If the temperature is increased to 2,800°C by increasing the voltage the power required is only 0.5 watts per c. p., and the efficiency is 12 %, but the life of the lamp is decreased at the same time to a few hours only, on account of the rapid vaporisation of the metal in the filament, the temperature of which comes very close to the melting point.

The efficiency η of a lamp in % is:

$$\eta = \frac{\textit{radiated lighting effect} \cdot 100}{\textit{total power consumption}}$$

Table 2. Efficiency of lamps.

Source of Light	%
Paraffin lamp	0.25
Vertical incandescent gas mantle	0.45
Carbon filament lamp	2.05
Metal filament lamp	5.40
Half-watt lamp	12.00
Flame arc lamp	13.20

One of the chief causes of the unsuitability commonly found in modern sources of light is their brilliancy, by which is meant that the strength of light per unit of surface of the glowing illuminant in c. p. per square centimetre, or beam intensity. In order that the brilliancy of a source of light shall not be dangerous to the eye it should be taken care that this does not exceed 0.4 c. p. per square centimetre.

Table 3. Intrinsic brilliancy of different sources of light.

Source of Light	Brilliancy — Normal c. p. per cm^2
Paraffin lamp	0.62—1.5
Incandescent gas mantle (vertical)	3.2—5.7
Acetylene	6.0—9.0
Carbon filament lamp 3.1 watts per normal c. p.	70—80
Carbon filament lamp 3.1 watts per normal c. p. (frosted)	0.5—1.0
Metal filament lamp 1.1 watts per normal c. p.	150
Metal filament lamp 1.1 watts per normal c. p. (frosted)	0.3—0.6
Half-watt lamp 0.5 watts per normal c. p.	800
Half-watt lamp 0.5 watts per normal c. p. (frosted)	1.2—1.6
Glow lamp	0.02
Moore's vacuum tube	0.04—0.25
DC arc lamp	3000

From the table we find that a powerful paraffin lamp is already of a brilliancy injurious to the eyes, and the brilliancy of a half-watt lamp which goes up to 800 c. p. per square centimetre should not be allowed in the line of sight. By hanging lamps in a suitable manner and providing them with proper reflectors and frosted globes the excessive brilliancy can be somewhat mitigated.

The colour of the light is another factor which is not unimportant. It is well known that we cannot exclude certain colours in lighting with ordinary incandescent lamps. It is particularly difficult to exclude the light rays of short wave length giving the blue and violet colours etc., since the rays of these colours are not present in large numbers.

The colour obtained from a source of light depends on the material which gives rise to the light. Incandescent bodies exhibit in general a continuous spectrum, *i. e.* a spectrum which resembles that of the sun. On account of the lower temperature and simple composition of the incandescent bodies we employ, the light is, however, not similar to sunlight, and the resulting colour is usually quite different.

Incandescent gases exhibit a line spectrum, and the light in general differs more from daylight than that given by incandescent solid bodies, compare for example the mercury vapour lamp.

In nearly all places now, use is made of the electric light, and in general incandescent lamps are used. Incandescent lamps require no attention and can be instantly lit. They give rise to no vitiation of the air and are noiseless. They also reduce the danger of fire or explosion, and can in a high degree be adapted to existing conditions, while they can be made in practically all sizes and are, above everything, cheap.

6. *Different kinds of Lamps.*

Carbon filament lamps are provided with a filament of carbonised fibre material enclosed in an exhausted glass bulb. They are seldom used for continuous lighting on account of the relatively large amount of energy they require, 3.1 to 3.3 watts per c. p., and their relatively short life, which is about 500 hours. They are besides susceptible to voltage variations by reason of the fact that the coefficient of resistance of carbon is negative.

Metal wire lamps, which are furnished with a metal filament, have displaced most of the other kinds of electric lamps. They were originally made from the metals tantalum, wolfram and osmium, or from an alloy of osmium and wolfram known as osram. At the present time they are nearly always made from wolfram since COOLIDGE in 1920 succeeded in producing drawn wolfram wire. The melting point of wolfram is approximately 3,160° C. In a vacuum 220 volt wolfram lamps have a filament with a diameter of 0.015 to 0.034 mm and a length of 725 to 1,040 mm respectively, the temperature being approximately 2,100°. By filling the lamp with a chemically inert gas (nitrogen or argon) at a pressure of 0.67 atmospheres at 0° C the vaporization of the filament is considerably reduced and the temperature can be increased to about 2,500° without greatly lowering the life of the lamp. A much more powerful light is obtained in this way. The gas filling the globe possesses the disadvantage that it is a conductor of heat, so that special precautions must be taken to reduce the heat radiation from the filament, and this is done by winding the filament wire into a spiral. In evacuated lamps this is not necessary as the vacuum acts as a heat insulator.

Wolfram at 0° has a specific resistance of 0.0637 ohms per metre and square millimetre. The resistance increases rapidly with increasing temperature, and at the working temperature for vacuum lamps is about 12 and for gas filled lamps about 16 times as great as it is at 0° C.

When switching on lamps a current rush is accordingly obtained which rises to 12 or 16 times that of the normal current and with a 25 c. p. vacuum lamp reaches its full value after 0.1 secs. and with a 100 c. p. lamp after 0.15 secs. The time for lighting a 500 watt gas filled lamp is about 0.3 secs., and is about 0.4 secs. for a 1,000 watt lamp.

On account of the great positive temperature coefficient, metal filament lamps are not so sensitive to voltage variations as carbon filament lamps. Vacuum lamps require, according to their size and voltage, between 1.25 and 0.8

Table 4. Candle power and Consumption of Lamps.

Vacuum Lamps				Gas Filled Lamps				
		110 volts	220 volts		110 volts		220 volts	
Mean horizontal c. p.	Total quantity of light lumens	Consumption watts	Consumption watts	Consumption watts	Mean horizontal c. p.	Total quant. of light lumens	Mean horizontal c. p.	Total quant. of light lumens
5	50	7	—	60	60	755	43	540
10	100	13	14	75	80	1005	63	790
16	160	18	21	100	108	1355	92	1155
25	250	25	30	200	250	3140	210	2640
32	320	32	36	300	407	5100	345	4330
50	500	50	55	500	717	9000	650	8150
100	1000	100	105	750	1155	14500	1015	12750

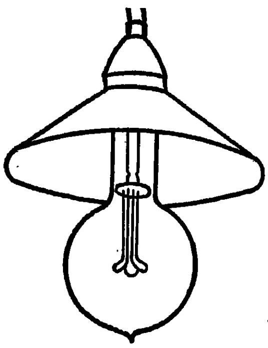


Fig. 9.

watts per c. p., and have a life of about 1,500 hours, if we understand by life the number of actual burning hours before the lamp gives out. Gas filled lamps require between 0.85 and 0.5 watts per c. p., and last on an average for 1,000 actual burning hours.

One cannot reckon on a consumption of 0.5 watts per c. p. except for the larger types of gas filled lamps of 300 c. p. and above.

Arc lamps are not very much used in these days either for indoor or outdoor lighting. The source of light consists partly of the glowing extremities of the carbon between which the arc is struck, and partly the carbon particles which are thrown out from the extremities and are brought to a white heat by the current in the arc. The temperature of the arc is exceedingly high, about 3,500°, so that the light of the lamp, with a suitable adjustment of the carbons, is rich in blue and violet rays, and resembles daylight more than the light obtained from any other artificial source. These lamps were accordingly often used formerly in places where it was necessary to differentiate between colours by artificial light.

A DC arc lamp with electrodes of carbon requires between 0.9 and 0.7 watts per c. p., and a flame arc lamp 0.25 to 0.17 watts per c. p.

Arc lamps require a good deal of attention as the carbons must be continually replaced, so that the running costs actually come out higher than those for gas filled incandescent lamps. In addition they emit gases and are not so safe as incandescent lamps, they are more expensive in first cost and cannot be installed in such suitable units. For these reasons they are now very little used.

For colour matching purposes incandescent lamps are now made with special screens, which are known as daylight lamps and which will soon displace arc lamps from this field also. Daylight lamps are gas filled incandescent lamps provided with a filter made by a patented process which consists of several coloured sheets of glass placed over one another according to definite rules, so that most of the red and yellow rays are absorbed, and the colour of the light approaches closely to that of daylight. The lamps are provided with reflectors, so that the absorption of light by the filter is to some extent compensated for.

Mercury vapour lamps give the well-known greenish coloured light. The illuminant is mercury vapour. The lamps consist of glass tubes which can be made up to one metre in length. At each end of the tube electrodes are placed. One electrode is in connection with the mercury container located at one end of the tube. The lamp is started by tilting the horizontal tube so that the mercury in the container comes in contact with the second electrode. Current then passes through the lamp. When the tube is brought back to its normal position the connection through the mercury is broken, and the tube is filled with glowing mercury vapour which acts as a conductor of electricity and as an illuminant. The light from the lamp is of a single colour and gives great clarity of detail to any object regarded. The brilliancy is not great, and the illuminant has the advantage of being widely spread out which makes for a good distribution of light.

The light, however, is cold and unpleasant. Faces appear greenish gray and corpse-like, so that the light is unsatisfactory for many purposes.

The quartz lamp is a smaller and more convenient lamp of a type similar to the mercury vapour lamp in which the illuminant is made of quartz.

Mercury lamps of 300 c. p. require 0.68 to 0.85 watts per c. p.

As such lamps, however, have no particular advantages over incandescent lamps and certainly have a number of disadvantages, they have not been used to any great extent. They are, for example, not easy to install, require mechanical arrangements for lighting them, cannot be worked in all positions etc.

A number of industrial undertakings in America are making use, it is understood, of mercury-vapour lamps.

The Moore light is produced in a rarified gas medium similar to that of a vacuum Geisler tube, and works with high tension electric current by which the tube is made to glow. This light is used for advertising purposes.

The glow lamp has the appearance of an ordinary incandescent lamp but is otherwise constructed somewhat on the same principle as a Moore vacuum tube. As the electrodes, however, are placed very close to each other, ordinary lighting pressures can be used. The light is of a reddish colour and as in the case of the Moore light the brilliancy is very small. The lamp is used for signalling, and also for advertising purposes and night-lights.

7. *Fittings and their effect on the illumination curves of Lamps.*

The functions of shades or reflectors are:

1) To break up and reflect the light and to give a certain diffusion so that it can be made use of in the best possible way.

2) To protect the eyes against the direct rays of the light.

All reflecting surfaces absorb a large part of the light. It is accordingly important to make the reflectors from a material which absorbs the light to the least possible extent. The colour of the reflector has an influence on its properties of light reflection.

Porcelain has shown itself to be very effective as a reflector, but as this material is bad from the point of view of strength shades of steel plate are being increasingly used with the active surfaces white enamelled. These shades absorb 35 % of the light falling on them, but are very satisfactory in other respects. Their efficiency is independent of the length of time they have been in use if they are kept clean. Less suitable reflectors are made of sheet metal covered with white lacquer. Where there is no risk of breaking the shade opal glass etc. may be used.

In certain types of fittings reflectors are furnished made either of glass or polished metal.

As regards the shape of the reflector, this is of particular importance, and must be determined with the greatest care. Likewise the position of the lamp with respect to the reflector is exceedingly important if good results are to be obtained.

It is entirely incorrect to imagine that equally good results can be obtained by the use of any kind of lamp in a certain fitting. The reflector should extend so far over the lamp that the eyes are not dazzled. Fig. 9 illustrates an arrangement which is often seen but which constitutes an example of how a shade should not be placed in respect to the position of the lamp.

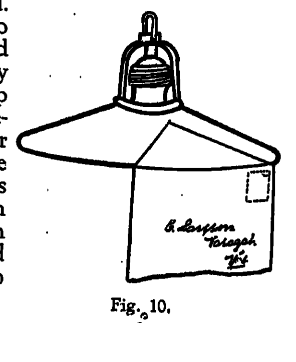


Fig. 10.

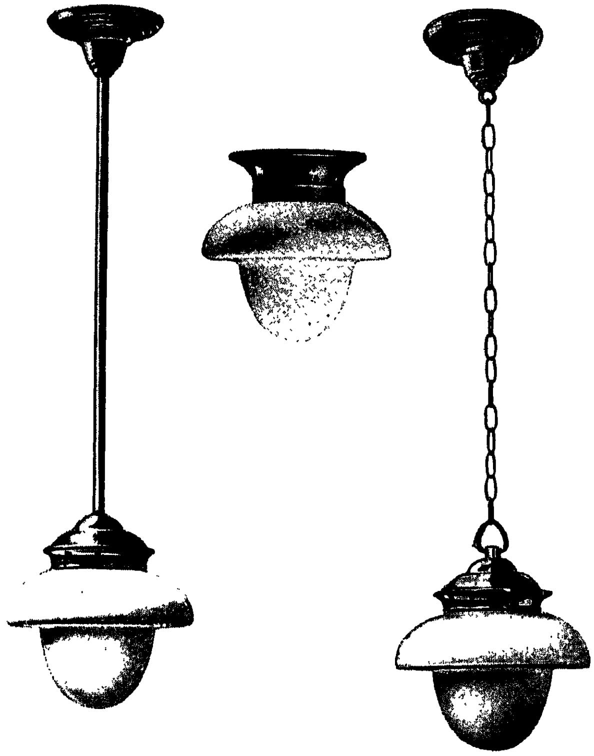


Fig. 11.

Fig. 10 also shows an improvised and incorrectly placed reflector which is not deep enough to protect the eyes against the light.

Fig. 11 shows a fitting which has been called the "Victoria Lamp" and which is very effective in rooms with light coloured ceilings and walls. The fitting is supplied in burnished or oxidized brass and has an oval globe. It is suitable for supporting by a rod or chain, or for mounting direct on the ceiling. It gives a pleasant light which is entirely free from glare and the light distributing properties are exceedingly good. Part of the light strikes the ceiling and is reflected down to the floor. The plain surface immediately around the globe is of clear glass so that the strongest light is thrown downwards. This fitting has the great advantage that it is easily kept clean and no dust can easily lodge on the polished surfaces. It is suitable for use in all rooms having light walls and ceilings such as offices, shops, schools, council chambers, and places where fine manufacturing work is carried on.

8. *Design of lighting installations.*

The design of lighting installations is in most cases done in a haphazard manner, or at most based on practital experience only. The number of lamps of a certain type is estimated, or else certain rule of thumb methods are made use of, as for example that for indoor lighting one should reckon with a certain number of candle power per unit of floor area. In this way a first class and economical installation can never be obtained.

From what has been said earlier in this article it will be appreciated that a lighting installation is not so simple that it can be left entirely, as is often done, to qualified wiremen. The problem of lighting actually gives rise to greater difficulties than most other problems which come under the consideration of engineers, since it is not only a matter involving physical and technical questions, but introduces also factors of a physiological and psychological nature.

There are still to be found many men at the head of all branches of industry who have a considerable distrust of everything included under the heading of theory, and regard anyone who seeks to assist practical ends with a certain amount of theory as incapable to say the least. It is however undoubtedly true in all modern industrial work that theoretical methods must be made use of in order that practical application may proceed along correct lines.

The chief requirement of a good lighting installation is that the resulting illumination shall in the greatest possible degree supply the want of daylight.

This implies:

1. That the lighting is sufficiently strong.
2. That it is evenly distributed.
3. That the source of light does not flicker.
4. That the source of light is not of such brilliancy as to cause any dazzling.
5. That the light is diffused while giving a satisfactory amount of contrast.
6. That the light is white, *i.e.* similar composition to daylight.

The strength of daylight when the sun is in the zenith reaches 150,000 lux, but this ligthing in the open has also to perform certain chemical changes in connection with vegetable growth, and it can be assumed that for ordinary optical requirements only, an illumination of 50 lux is sufficient without giving rise to any eyestrain. The lighting can vary considerably according to requirements and for various purposes the requirements are generally as given in table 5.

Table 5. Necessary illumination in lux for different requirements.

Kind of room lighted	Average illumination at a height of 1 m above the floor	Total illumination average at the working level
Entrances, Stairways, Corridors ...	10—15	—
Living rooms ...	20—40	—
Schools and Halls ...	30—40	50—60
Drawing offices and Business Premises ...	40—60	60—100
Shops ...	40—80	—
Stores ...	10—25	—
Cotton Mills...	20—30	—
Weaving sheds for dark material, for the finer light coloured materials, and workshops handling dark materials etc. ...	40—50	60—100
Heavy forging foundry and rolling mill work ...	15—25	15—35
Finer joinery work, watch-making and finer types of mechanical work ...	50—60	100—150

By evenness of illumination is meant the relation between the greatest and least illumination upon a given surface.

For example, if the lowest illumination on a working surface = 30 lux and the highest = 50 lux, the evenness = $\frac{30}{50} = 0.6$.

As previously pointed out, most lamps do not give the same strength of illumination in all directions, so

Table 6. Values of transmission and reflection characteristics for different materials.

Material	Thickness mm	Coeft. of Transference: Focussed light %	Coeft. of Transference: Diffused light %	Coeft. of Transference: Coeft. of diffusing %	Coeft. of Reflection: Focussed light %	Coeft. of Reflection: Diffused light %	Coeft. of Reflection: Coeft. of diffusion %
Milky glass	2.3	0.05	13	1.0	5	68	1.0
" "	1.6	0.15	35	1.0	3.5	71	0.78
Opal "	2.0	2.5	56	0.78	3.5	37	0.73
" "	2.0	63	15	0.85	1	10	0.70
Ground " flat	1.8	5.5	54	0.42	3.5	25	0.80
" " corrugated					0.1	17	0.75
Frosted "	1.8	48	22	0.2	7.5	15.5	0.80
Enamel No. 1	—	—	—	—	1	52	0.86
" " 2	—	—	—	—	0.4	64	0.78
" " 3	—	—	—	—	0.1	69	0.80
Silver plated copper foil	—	—	—	—	67	9	0.23
Aluminium foil	—	—	—	—	73	12	0.28

that we are obliged to attempt to correct this by suitably constructed reflectors, both as regards the general illumination of the floor, and the illumination at the working position. A reflector always means increased illumination in the lower hemisphere of the lamp although part of the light is always absorbed. Simple reflectors absorb up to 50 % of the illumination thrown upon them.

Figure 12 gives the lighting curves for a deep shade, the efficiency of which is 0.55, but in spite of this it is justified economically, since by its use a large part of the light from the upper hemisphere is directed downwards. We can accordingly say definitely that the strength of the lighting, besides depending on the source of illumination depends considerably upon the fitting. The form of the reflector and the material from which it is made is of very great importance. The lighting curve for a lamp is accordingly altered to a considerable extent by the reflector.

Reflectors are of two kinds, those giving specular reflection and those giving diffused reflection. With specular reflection the ordinary law applies that the angle of incidence is equal to the angle of reflection. The strength of the reflected ray depends on the absorption and colour of the reflecting surface and upon the colour of the light. As regards reflection which is completely diffuse the above physical law does not hold good, and the problem of calculation is considerably more involved. The stream of light is also not concentrated in any definite direction. Reflectors commonly used in lamp fittings have properties of both mirror and diffuse reflection.

The efficiency of the designs of reflectors most commonly used is between 0.6 and 0.8. By the efficiency of a fitting is meant the relation between the stream of light which is obtained from the naked lamp within the angle which the fitting would permit, and that obtained from the lamp when placed in the fitting.

The illumination depends not only upon the fitting, but also to a great degree upon the colour of the surface illuminated. The colour of the floor, ceiling and walls of a room, and also the colour of the contents of the room are of great importance in indoor lighting. Part of the outgoing stream of light is reflected back by the surfaces which it strikes, so that the capabilities of the ceiling and walls as reflectors have some considerable influence.

On account of this we often speak of the efficiency of a room as regards illumination, and by this is meant the relation between the total stream of light which strikes the working surface, and the total stream of light which leaves the lamps in their fittings.

The efficiency of a room is accordingly dependent upon the fittings.

The efficiencies of rooms with direct and semi-indirect lighting lie between 0.2 and 0.5, and the figure 0.5 must only be used in rooms with extremely light ceilings and walls, drawing offices etc.

If a room is made up of several surfaces A with different coefficients of reflection α we may calculate the mean coefficient of reflector α_m in the following manner:

$$\alpha_m = \frac{\Sigma(\alpha_1 A_1 + \alpha_2 A_2 + \text{---})}{\Sigma(A_1 + A_2 + \text{---})}$$

As regards factory lighting the above particulars lead to the following principles:

a) From the optical standpoint:

Paint the shops white whenever the purpose for which they are to be used permits it.

Keep the walls and ceilings clean.

b) From the psychological and physiological standpoint:

Paint the shops white, keep them clean everywhere.

Cleanliness of the ceiling and walls not only assists lighting, but also constitutes a psychological factor of great value which in most cases affects the working conditions beneficially and is also important in the question of health.

When designing a lighting installation the contractor must obtain complete information regarding special requirements. When the lighting of a factory is in question, and the methods of working are not fully understood by the contractor, it is necessary to make a careful investigation of the actual requirements of the workpeople so that the lighting will meet these requirements thoroughly.

According to the characteristics of the job, the lighting may be arranged as:

1) Distributed lighting,
2) Concentrated lighting,
3) Combined distributed and concentrated lighting.

Which of these three arrangements can be made most suitable depends on the character of the factory and rooms.

It is difficult to arrange suitable distributed lighting where there exists shafting, belts etc. When distributed lighting is to be used, the semi-indirect lighting is recommended if the shops etc. are so arranged as to make it possible. Entirely indirect lighting cannot in general be used in factories, as the running cost would be too high and the ceiling would have to be kept white and extremely clean, and this condition, with the exception of factories producing the finer kinds of light goods, is difficult to obtain without considerable expenditure.

In cases where concentrated lighting of individul positions is taken in hand, care must be taken that sufficient distributed lighting is provided for traffic between the different positions. General lighting should also not be too weak, especially in cases where one workman has conti-

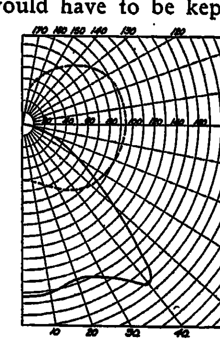


Fig. 12.

Fig. 13.

nually to move from one place to another, since if this movement involves the passing through dark places, to which the eyes endeavour to accommodate themselves, it gives rise in time to tiring, not only the eyes, but also the nerves and the brain. The same thing occurs when the man takes his eyes off his work and looks at other parts of the room.

Figure 13 shows a suitably arranged concentrated lighting. The only light meeting the eyes is that reflected from the work itself.

Electric lighting with AC of low frequency is not suitable, as the rapid flickering which is caused is particularly troublesome. At 25 cycles and a lighting voltage of 220 this flickering is very noticeable. If one is obliged to make use of this frequency the voltage should be transformed down, or else the power required for lighting should be converted to continuous current. With lower pressures, for example 110 volts or 65 volts, the lamps have a smaller resistance, and accordingly thicker filaments than they have at 220 volts. The filament has thus a greater heat capacity and does not have time to cool so much between each half period, and the light radiated by the filament is accordingly more steady. At the same time, transforming down means that the current used by the lamps is higher and the installation cost will be greater. Suitably arranged shades and reflectors can be made to reduce the effect of the flickering.

Table 7. Coefficient of reflection in % for different wall and ceiling coverings.

	%
White ceiling, clean	80
" " slightly soiled	40
" cartridge paper	82
" writing paper	70
Yellow draughting paper	56
" wallpaper	40
Blue "	25
Dark blue "	13
Light red "	36
Brown "	13
Yellow distempered wall, clean	40
" " " soiled	20
Dark cloth	1
" velvet	0.4

In order to have the lighting evenly distributed it might perhaps be assumed that this should be done by using a very large number of lighting points of suitable power. An installation put in on these principles, would however, be exceedingly expensive.

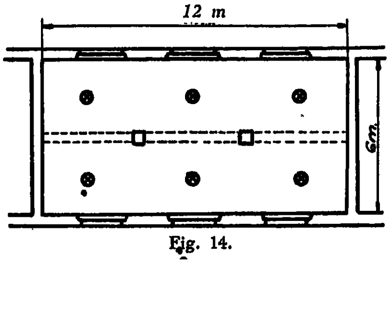


Fig. 14.

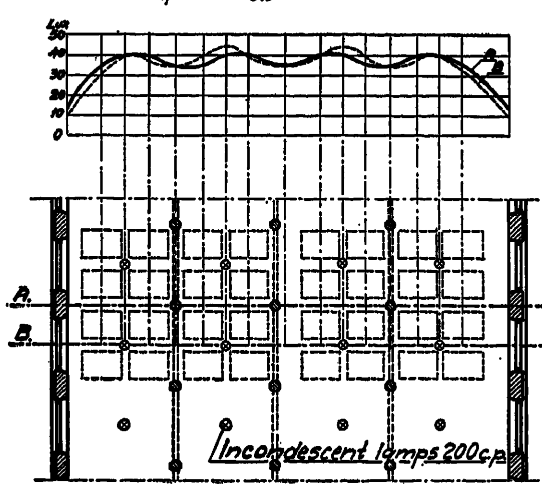
To use small units and to place them close together is uneconomical, partly because small lamps have a higher current consumption per candle power, and also because the installation costs are greater. Accordingly the number of points should be as few as possible, and suitable fittings should be made use of to obtain a good distribution of light.

Fig. 15.

9. *Examples of lighting installations.*

In a drawing office or similar room where the ceiling and the upper parts of the walls may be white and can be kept clean, one would choose distributed lighting, either indirect or semi-indirect, (Fig. 14). For example: a drawing office is 12 m long, 6 m broad and 5 m high, and is divided longitudinally by a beam 40 cms high which is carried by two pillars, figure 14. The ceiling and walls are white and the room has six windows which are covered, after dark, by white blinds. The efficiency of the room if the fittings are suitably chosen can be taken as 0.5. The beam and the pillars divide the room naturally into six parts, so that one could hardly consider a smaller number than six lighting points. The fittings are arranged for semi-indirect lighting. In accordance with table 5 we should assume an illumination of 60 to 100 lux. If we took 90 lux the necessary light quantity would be:

$$\Phi = \frac{E \cdot A}{\eta} = \frac{90 \cdot 72}{0.5} = 12{,}960 \text{ lumens.}$$



A = Illuminating curve for sect. A—A, 90 cm above the floor.
B = " " " " B—B, 90 " " " "

Fig. 16.

Fig. 17.

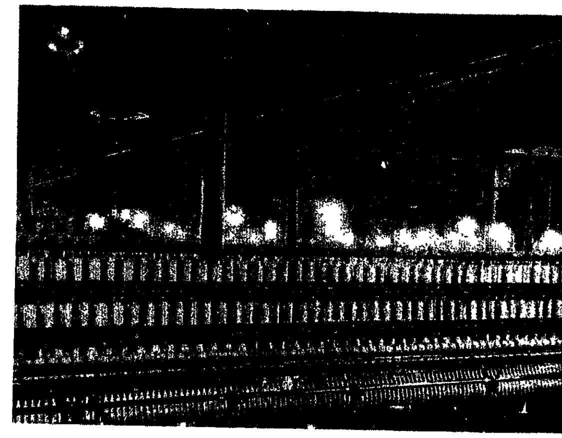


Fig. 19.

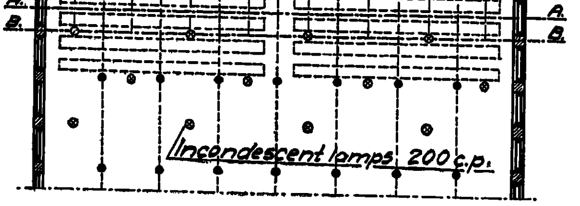
Each lamp has thus to supply 2,160 lumens. If the lamps are taken as giving 2,000 lumens the illuminations will be:

$$E = \frac{2000 \cdot 6 \cdot 0.5}{72} = 83.3 \text{ lux},$$

which can be considered as satisfactory.

Figure 15 shows an example of lighting in a weaving shed. The shed is 3.85 m high with white painted ceiling, and walls of a greyish white tint. Distributed lighting is adopted which is semi-indirect, using the white roof as a reflector, there being no transmission shafting etc. to interfere with the reflection of the light. The lamps are 200 c. p. metallic filament lamps with the lower half of the bulb frosted, mounted direct on the ceiling in ordinary lamp holders, and placed in relation to the looms as shown in the plan in fig. 16. The plan shows also illuminating curves for the sections A and B at a height of 0.9 m above the ground. The mean illumination at this height is 36 lux.

Minimum illumination at the working level	= 22 lux.
Maximum " " " " "	= 44 "
Evenness of illumination $\frac{22}{44}$	= 0.5
Lighting consumption per loom	= 50 watts.



A = Illuminating curve for sect. A—A, 90 cm above the floor.
B = " " " " B—B, 90 " " " "
Fig. 18.

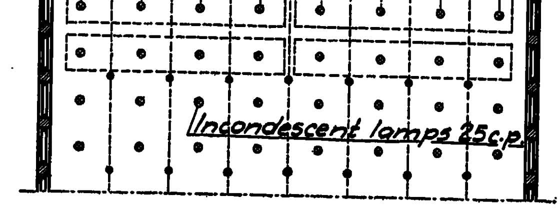
This lighting can be regarded as satisfactory in a weaving shed for light coloured materials, but would not be suitable for dark coloured cloth.

If the lighting is in use 400 hours per year and the cost of power is reckoned to be 1 d. per kWh, the cost of lighting per loom is 1/8 d. per year. Figure 17 shows the lighting in a spinning mill with group driven spinning frames. The height of the room is 3.9 m. The walls and ceiling are painted in a greyish white colour. Distributed lighting is used and is direct. The lamps are metallic filament of 200 c. p. and carried in fittings with white enamelled shades about 0.7 m from ceiling in order to come below the transmission arrangements; they are accordingly about 3.2 m above the floor. The position of the lamps and two curves of illumination on sections A and B, taken at a height of 0.9 m above the floor are in accordance with the plan, figure 18.

The mean illumination at the above height is 14 lux.

The minimum illumination at the working level	= 7 lux.
" maximum " " " " "	= 19 "
" evenness of lighting " " " "	= 0.37.

The power consumption per spinning frame is 200 watts, and the costs per year covering 400 hours at 1 d. per kWh come to 6/8 d.



A = Illuminating curve for sect. A—A, 90 cm above the floor.
B = " " " " B—B, 90 " " " "
Fig. 20.

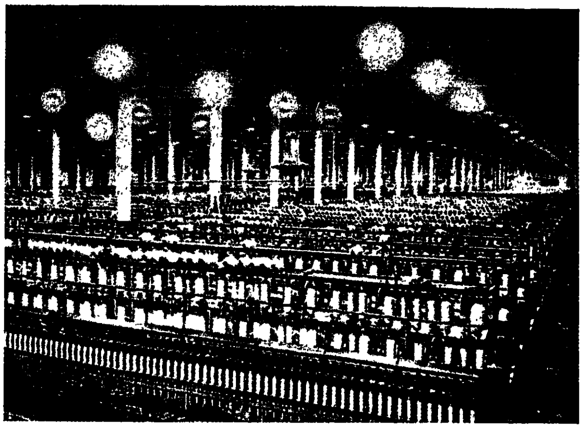


Fig. 21.

The lighting in this mill must be regarded as particularly unsatisfactory, since the illumination for the working conditions should be between 20 and 30 lux.

Figure 19 shows the illumination in a mule shed which is about 4 m high. Distributed lighting is used. Ceilings and walls are painted a greyish white colour. The lamps are 25 c. p. metallic filament, carried in pendants with lacquered shades. They are placed at a height of 2 m above the floor.

The position of the lamps and the illumination curves at 0.9 m above the floor on sections A and B are in accordance with figure 20.

The mean illumination at the given height is 6 lux.

The minimum illumination at the working level = 4 lux
„ maximum „ „ „ „ „ = 7.6 „
„ evenness of „ „ „ „ „ = 0.53 „
The power consumption per spinning mule = 120 watts.

The lighting in this room is quite insufficient and should certainly not be allowed. In order to bring it within suitable limits the value should be quadrupled.

Figure 21 shows an example of a good distributed lighting system in a cotton mill. Three 60 watt lamps are placed between each pair of spinning frames. As shown in the illustration the result is very satisfactory. The lamps are furnished with suitable fittings. The power consumption is 90 watts per spinning frame.

As previously pointed out, lighting should not be completely diffused, since the ability of the eye to appreciate an object is derived from the colour and contrast properties of the light which enters it.

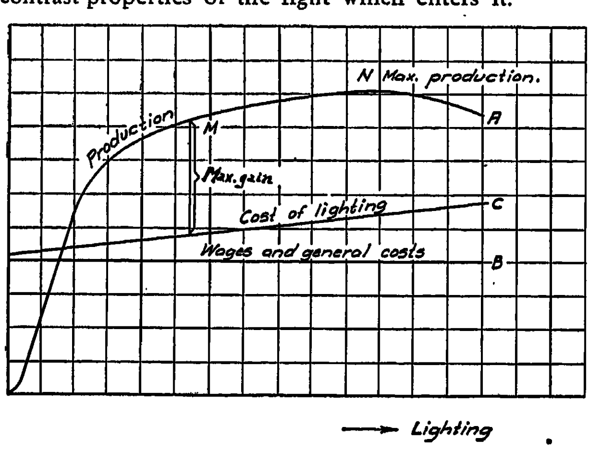


Fig. 22. Diagram showing the dependence of production on lighting.

With fully diffused light the speed of work is reduced on account of the difficulty of visualising the position of different surfaces and determining their distance from the eyes.

In order that it may be possible in textile work to locate thread breakages and other troubles easily and without eyestrain, and put these things right with the least possible loss of time, it is necessary to have exceedingly good lighting. In a weaving shed it is often found that distributed lighting is not sufficient, especially in sheds where there is overhead transmission.

At some places it is usual accordingly to use lamps arranged at the working positions, in addition to the general lighting, and these lamps are automatically lit when the looms come to rest. By this means it is not only possible to save the cost of running these lamps while the loom is stopped, but at the same time it is easy to see which looms are not running, and this is an advantage where the weaver has to attend to from 12 to 16 automatic looms. When he has put the trouble right and started the loom again he does not require such strong illumination and the lamp is automatically extinguished.

Good distributed lighting in a weaving shed for light materials should be between 35 and 40 lux, and for dark materials or light materials employing a very fine thread, 40 to 50 lux.

In spinning mills a good general illumination is a greater advantage than concentrated lighting, and this can be obtained from fittings fixed direct to the ceiling, or pendants of a length suited to the conditions. The illumination should be 20 to 30 lux.

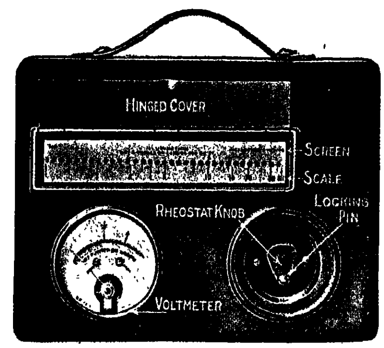


Fig. 23.

The full advantages of electric lighting are only obtained when all the factors have been carefully dealt with in each special case.

Suitable lamps and suitable fittings, together with proper fixing are also factors which must not be forgotten. The principle of supporting lamps should be, that any having a greater brilliancy than 5 c. p. per square centimetre should not be hung where the direct rays can meet the eyes. They must accordingly be screened when the rays from them make an angle of less than 30° with the horizontal.

Regarding lighting in rooms where there is great risk of fire, such as weaving sheds, spinning mills etc., it should be noted that the Swedish practice is to provide lamps with dustproof fittings. The fitting in general, however, has the disadvantage that the lamps get hotter than usual, and this tends to reduce their life. In general the temperature surrounding the lamps should be kept as low as possible, since otherwise the heat cannot be dissipated and this leads to a higher temperature of the filaments.

10. *Lighting Costs.*

Lighting costs in a factory are relatively small compared with the remaining costs of production. In a weaving shed with automatic looms and good lighting, in accordance with fig. 15, we have seen that the costs per loom and year amount to 1/8 d. If a weaver operates 12 looms, the cost per weaver and year is ac-

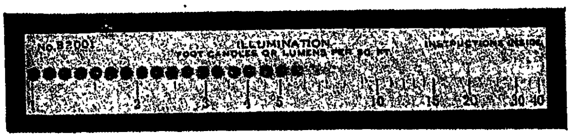


Fig. 24.

cordingly £ 1. If this sum is compared with the power costs* for running the looms and the interest and depreciation costs for 12 looms, and the same costs for the space occupied, etc., it requires practically no investigation to state definitely that it will pay well to use such good lighting that full and satisfactory production is obtained while the lighting is in use. Assume that the lighting in this particular example is reduced by half, *i. e.,* 25 watts per loom. The saving in power consumption amounts to 10 d. per loom and year, but we may be certain that the decrease in production during the 400 hours of the year in which the lighting is in use, owing to the fact that neither the personnel nor the expensive installation is fully and properly utilised, will involve a far greater loss than 10 d. per loom.

A question of a social welfare nature, but not of less importance on that account, is that one should look after the operatives and not use lighting which will involve eye trouble at an early age, since this, if everything is measured in terms of production only, will certainly not pay in the long run.

In the mule shed, fig. 19, the power consumption is 120 watts per machine. If this lighting is quadrupled the power goes up to 480, or say 500 watts, and the mean illumination is 25 lux.

The lighting costs of 400 hours per year at the same cost of energy as before then reaches 1.6.8 d. Such a machine is operated by four work people, so that the lighting costs come out at 4/2 d. per operative as against the present 1/0½ d. per year. If we consider what a spinning mill costs and the space which it takes up, and taking all factors into consideration, we can without making any experiments definitely state that it will pay to increase the illumination to 25 lux. In addition to the fact that work can be performed quicker, since the operatives can see better, the speed is also increased, owing to the fact that all the work people are more wakeful in the better light.

At the same time in this connection it may be pointed out that production will not increase when the lighting has reached a certain limiting value. If the lighting is increased further the production will decrease again because the stronger illumination will be an actual hindrance to the speed of working.

In the diagram, fig. 22, curve A gives the production characteristics for an operative with different lighting and curve B the constant running costs, wages**, interest, depreciation, etc. Curve C gives the costs of lighting. It is seen that the production reaches at M its best value with the least outlay. If the lighting is increased the production reaches its highest value at N, but the total costs are greater.

11. *An instrument for testing illumination.*

For making measurements of the value of illumination in factories etc., ordinary photometers of the laboratory type are not suitable as they are awkward in use, when it is necessary to make an estimation of the illumination on a horizontal plane. An American firm has accordingly placed on the market a small and convenient instrument which is shown in figure 23.

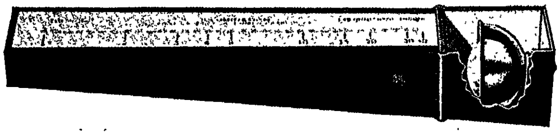


Fig. 25.

This instrument, which is known as a foot-candle-meter, is 20 cms long, 15 cms wide, and 4 cms deep, so that it can be carried in an ordinary overcoat pocket. The illumination is given in foot candles or lumens per American square foot (1 foot candle = 11.98 lux). The instrument works on the old grease-spot principle, and is provided with a white scale having a series of small round transparent spots, figure 24. This scale is illuminated from beneath in the manner shown in figure 25. The spots to the right are more strongly lighted than those to the left. As the scale is lighted from below, it is clear that at the point where the appearance of the spots changes from darker to lighter than that of the remaining surface of the scale they are approximately equally lighted from both sides. The reading is taken on the scale opposite to the spot which is least visible, compare fig. 24.

The current for the illuminating lamp is obtained from a dry battery contained in the instrument, and a rheostat is provided for regulation. As it is important that the lamp should be supplied with the correct voltage in order that the strength of light shall always be the same, the apparatus is also fitted with a voltmeter on which the correct voltage for normal use is marked.

This apparatus is certainly not a precision instrument, but is perfectly satisfactory for estimating the illumination in factories and such places. It has the great advantage that it can be easily placed on any surface at which it is desired to measure the illumination.

* We here assume a fixed charge per kW per year and a relatively low price per kWh.

** The curve does not apply for piece-work.

Vesteras 192[illegible] Vestmanlands Allehanda Printing Co.

ASEA-JOURNAL

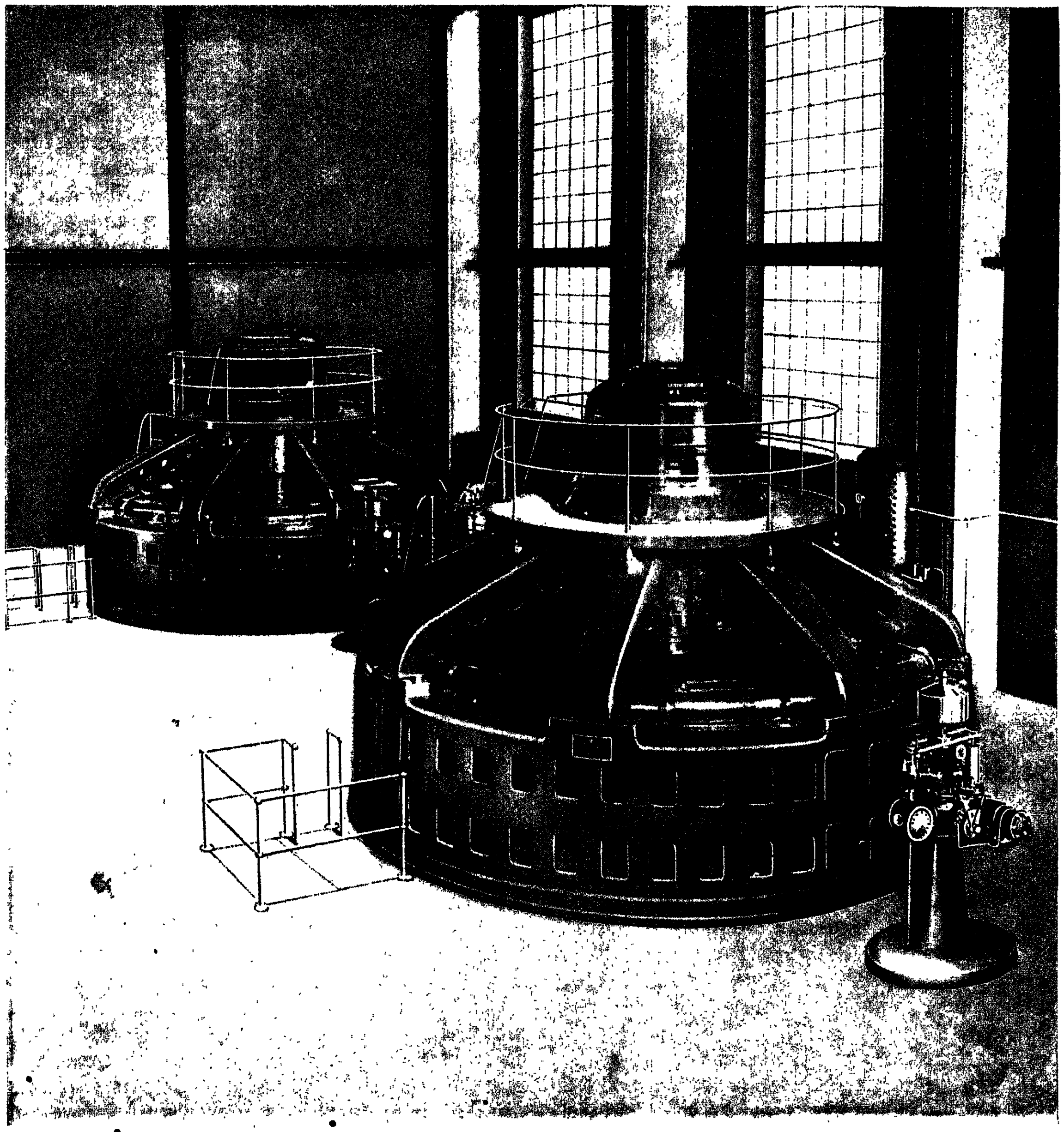
ALLMÄNNA SVENSKA
ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD.
5, CHANCERY LANE—LONDON

VOL. II
1925

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesterås, Sweden.
Permission is given to reprint articles or extracts from this journal,
on condition that the name — Asea-Journal — is clearly stated.

JUNE
No. 6



The Northern Canada Power Co's power station on the Quinze River, Canada. Two vertical Asea AC generators each for 10,000 kVA at 187 r.p.m., 25 cycles, 11,000 volts.

THREE-PHASE GENERATORS FOR QUINZE, CANADA.

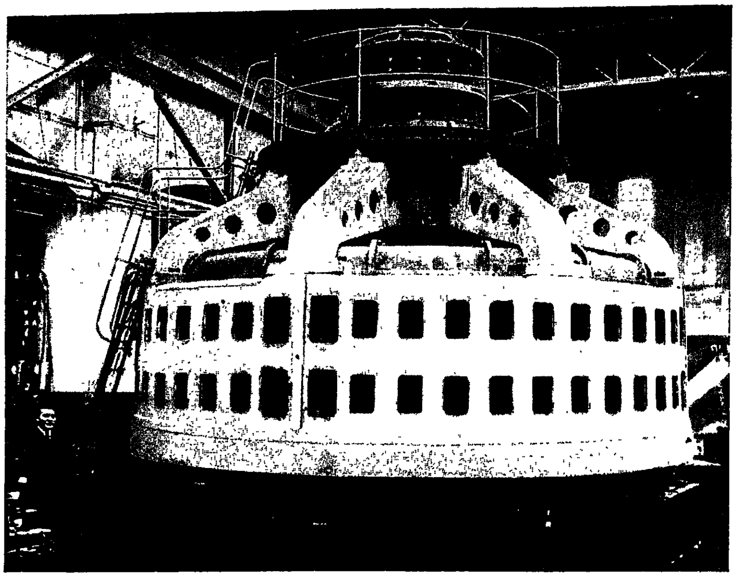


Fig. 1. 10,000 kVA three-phase generator for Quinze erected for test.

In Canada, the electrification of the water power resources is being pushed forward with the greatest determination, and many years ago Asea supplied alternators to this country for direct coupling to water turbines. During the recent year Asea delivered a number of such generators both for municipal and privately owned plants, and most of these were of the vertical type which is usual in Canada and for very considerable outputs. Among the largest are the two generators for the Northern Canada Power Company's station on the Quinze River.

This firm have for a long time had a number of power stations running in the province of Ontario which supply power to the great mines in the Porcupine district. These for a year or more have been requiring more power than the stations could deliver, and accordingly in June 1923 the company commenced the erection of a plant at a fall owned by them known as the Kakake Falls on the Quinze River, which is known lower down as the Ottawa River. The fall is situated in the province of Quebec near the Ontario boundary and about 125 miles from Porcupine. The available power amounts to about 60,000 h.p., the height of fall being approximately 27 metres, and a third part of this has now been electrified with two units consisting of single runner water turbines designed for 10,000 h.p. with a fall of 21.4 and 13,400 h.p. with a fall of 27.4 metres, and running at 187 r.p.m. These are direct coupled to Asea generators with direct connected exciters and upper supporting bearings dimensioned to carry the whole of the rotating weight, amounting to about 125 tons.

Each generator is designed for a continuous output of 10,000 kVA at 187 r.p.m., 25 cycles, 11,000 volts and power factor 0.8. The exciter voltage is 220.

As mentioned above the generators are of the vertical arrangement and their shafts are provided with flanges for direct coupling to the turbines.

The stator frame and covers are of cast iron and carefully designed for resisting deformation and vibration, while permitting good cooling, both for the windings and core. To facilitate transport the stator is divided into four parts which are held together with bolts. The core is made fast in the stator frame in the usual manner and is firmly held between press flanges. It is divided up into a number of sections, radial cooling ducts being left between each. The insulation between the laminations is in accordance with Asea's invariable practice of thin paper pasted on in a special machine before cutting and punching the plates. The stator winding is a two-plane coil winding carried in open slots in which it is held by fibre wedges. Since the number of poles is small on account of the low periodicity, while the machine on account of its large output had to be of large diameter, it has been possible to divide the winding among a large number of slots per pole

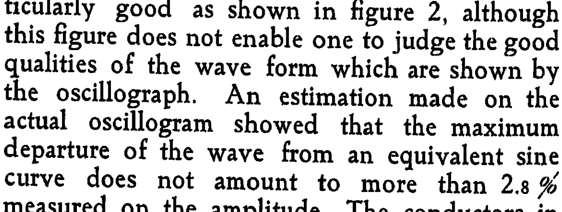


Fig. 2. Oscillograph diagram of voltage wave at no load.

and phase. The voltage wave obtained is particularly good as shown in figure 2, although this figure does not enable one to judge the good qualities of the wave form which are shown by the oscillograph. An estimation made on the actual oscillogram showed that the maximum departure of the wave from an equivalent sine curve does not amount to more than 2.8 % measured on the amplitude. The conductors in each slot are, in order to make manufacture more easy and to reduce eddy-current losses, divided into three parts, each with impregnated

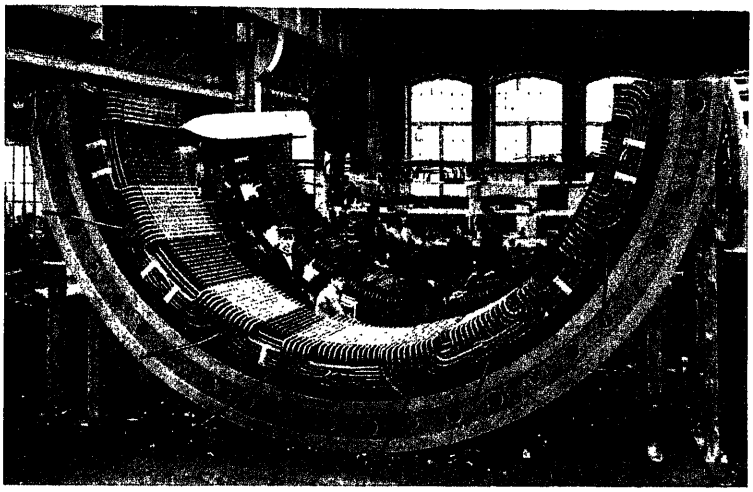


Fig. 3. Stator halves during winding.

double cotton covering. The parts belonging to one conductor are completely insulated from the remaining conductors in the same slot by special insulating division pieces of mica. These, in accordance with Asea's standard, are moulded beforehand to a U section of correct dimensions and are laid together in pairs so as to form a tube surrounding the sections of conductor. They are jointed together with varnish. After all the conductors in one slot have been varnished over they are wrapped round with mica pasted on to thin paper until the required thickness is obtained. After this, the insulation which is still loose is treated in a special machine having rotating rollers, and

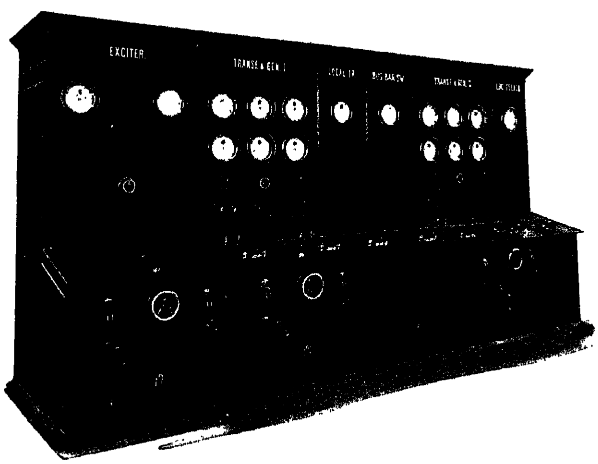


Fig. 4. Switchboard at the power station.

the coil is well warmed up during this treatment. The varnish is melted and the surplus runs out at the ends under the pressure, carrying with it any air imprisoned in the interior. Air is in this way excluded in a very effective manner from the interior of the coil and the chemical changes which can take place in its presence, and damage the insulation, are prevented.

In the outer part of the winding each conductor is additionally insulated with strips of specially impregnated cloth, and all the conductors coming from one slot are insulated over all with a layer of impregnated tape and finally painted with insulating and black varnish. Naturally all the air spaces and leakage paths are so well dimensioned that flash over or creepage between different phases or to iron is made impossible. As the end windings outside the iron are naturally relatively long on account of the frequency, they are strongly clamped so that they will suffer no damage when strained by the occurence of short circuits or sudden load alterations. The clamping arrangement consists of two circles of axially placed bolts screwed into the press flanges, one set inside and the other outside the coil ends. By suitably shaped separators of insulating material and well insulated bridge pieces of wrought iron the coils are firmly held between the clamping bolts which are thus well insulated from the windings, and the insulation described is further strengthened at the studs and between phases. All surfaces are painted over with varnish. The stator winding has six terminals, two for each phase.

The rotor is made with the arms and boss in one piece, of cast iron, and made fast to the shaft with keys and shrink rings. It carries the magnet ring made in two parts of cast steel. The rings are divided by a central radial ven-

Fig. 5. The rear side of the switchboard.

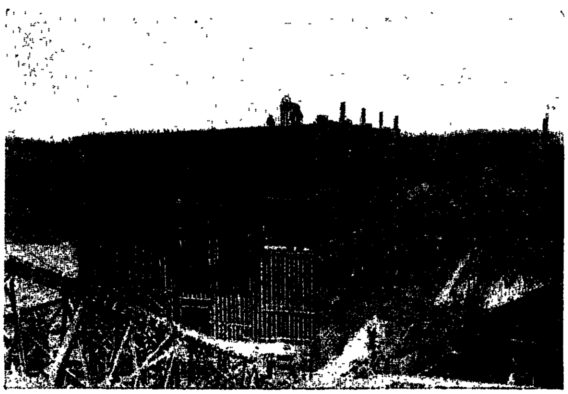


Fig. 6. Power station during building.

is quite clear from the small discrepancy between the voltage curve obtained and the true sine curve. That they can be made massive in spite of the open slots employed depends on the fact that the air gap is made sufficiently great. The eddy-current losses have also been kept exceedingly small and no appreciable heating takes place in the pole shoes.

The field windings are carried out in copper strip wound on edge and insulated between turns with varnish impregnated paper, while between windings and iron, collars and cylinders of presspahn are used. The leads to the rotor

tilating duct which allows cooling air access to the pole cores, and also to special holes in the poles through which it reaches the duct in the middle of the pole shoe and from there passes into ducts in the stator. Although the air is of course somewhat warmed during its passage through the various parts of the rotor — it is intended that these parts should also be cooled as much as possible — it reaches the centre of the stator relatively cool, so that a powerful cooling of this is possible and no great local heating can occur. This is controlled further by thermo elements which show that the temperature rise is practically the same over the whole extent of the core.

The pole cores are also of cast steel and are made in one piece with the massive pole shoes. The cores are fixed to the magnet ring by bolts of special steel. This construction can be used in the present case since the runaway speed, although taken as being 100 % above the normal, is not so great that the stresses in the pole fixing bolts cannot be kept within the allowable value. The shape of the pole shoes and their position are very carefully designed, which

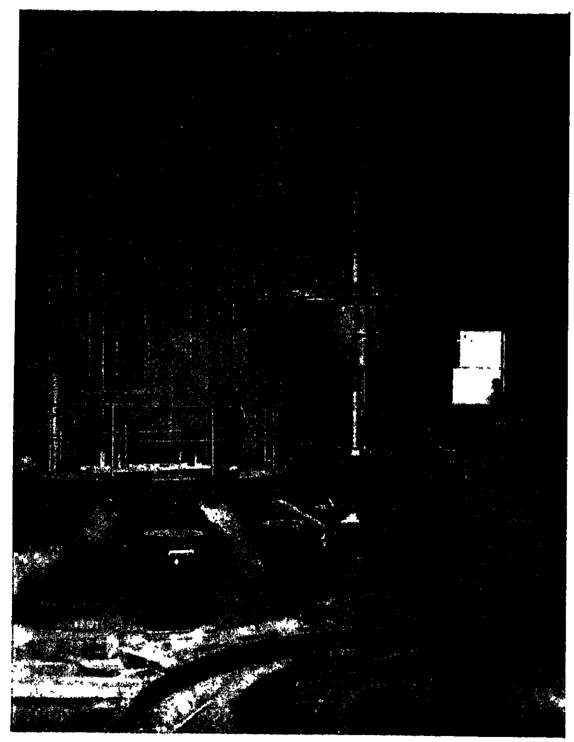


Fig. 8. Lowering the rotor of the generator into position.

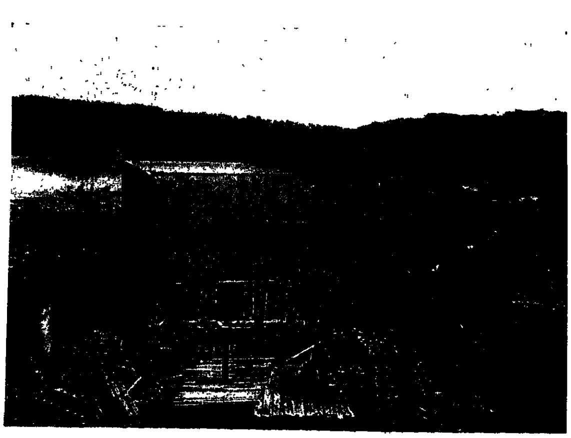


Fig. 7. Power station at the end of the first stage. In the background the Quinze River, and on the right the dam and pipe line.

winding are taken through the hollow shaft and brought out beneath the exciter to the sliprings which are placed immediately above the supporting bearing. Sliprings are often placed at the end of the shaft above the exciter, but in the present case, on account of the large size of the exciter, they would have been less accessible if so fitted, and in their actual position they are easy of access for inspection from the same platform which is used for inspecting the supporting bearing and the exciter. The rings themselves are as usual of cast iron, and carbon brushes are used.

The shaft is forged from best quality steel and properly designed for resisting the mecha-

nical and magnetic stresses as well as the suppression of vibration. At the lower end there is a forged flange for coupling to the turbine shaft and at the upper end it is provided with a locking ring for fixing the bearing flange which is carried on the surface of the supporting bearing and also with a machined end for receiving the armature of the exciter.

There are three bearings consisting of a supporting bearing and guide bearing above the machine and a lower guide bearing placed under the rotor. The supporting bearing is a segmental bearing of Asea's standard design and dimensioned for taking up the whole of the rotating weight referred to above, of which approximately half is due to the rotating parts of the turbine and half to unbalanced water pressure. The guide bearings are ordinary babbitted sleeve

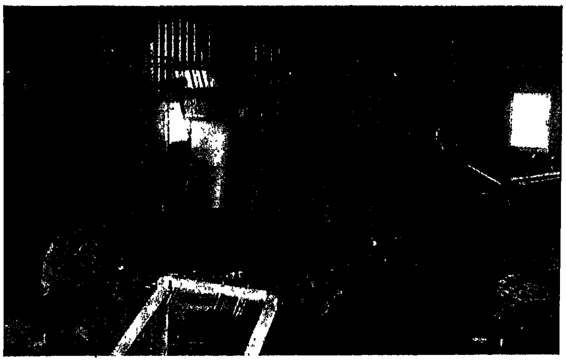


Fig. 9. The second generator under erection. In the background the temporary wall and some of the transformers.

bearings. Lubrication is effected under pressure from a pump driven from the turbine shaft which draws oil from a container where it is cooled and filtered and forces it up to the supporting bearing. From there it runs down to the upper guide bearing and then into the lower guide bearing from which it returns to the container. By means of suitably arranged control oil cocks and inspection glasses etc. the distribution of the oil and the functioning of the lubricating system can be observed and controlled. The supporting bearing housing is equipped with an original and practical detail, namely self-contained lighting, so that when inspecting etc. a hand lamp with its awkward flexible connection is not required.

The upper supporting and guide bearing and the exciter are carried on the upper arm-cross which rests on the stator frame and has heavy arms held with bolts to a central boss which forms an oil casing for the bearing. Both arms and boss are of cast iron. The lower arm-cross,

Fig. 10. View of Quinze River and the workmen's houses.

which only carries the lower guide bearing and brake arrangement, is also of cast iron but is more lightly dimensioned. It is fixed to the base ring which is of cast iron grouted to the foundation and which acts as a support for the stator frame.

The brake arrangement consists of four hydraulic jacks, the stationary parts of which are held on the arms of the lower arm-cross, and the moving parts of which apply a brake against the rotor ring which is specially furnished on its under side for this purpose. When the machine is to be brought to a standstill the brake blocks are pressed against the ring with a suitable pressure and they can be locked in such a position that the unit is unable to start off of its own accord in the event of water leaking into the turbine. This brake arrangement is also used during erection and dismantling, as by applying a higher pressure the rotor can be lifted sufficiently to allow inspection etc. to be carried out as required.

The exciter, as will have been made clear from the foregoing, is provided with an armature carried

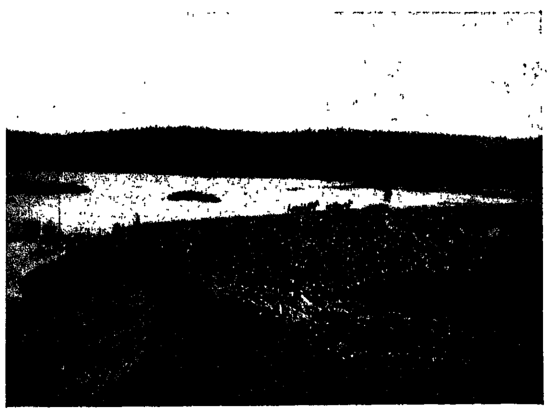


Fig. 11. Combined roadway and dam.

direct on the generator shaft while its yoke is carried on a base ring resting on the housing of the supporting bearing. In accordance with usual practice it is provided with laminated main poles and solid commutating poles fixed to the yoke by bolts screwed from the outside. The field coils are insulated from the iron with presspahn and impregnated cloth. The rotor and commutator are both carried on a common cast iron spider which is fixed on the generator shaft in such a manner that it can be easily removed when necessary. The armature core consists of paper insulated laminations and is provided with radial ventilating ducts. The winding is made up of former wound coils consisting of cotton covered and impregnated copper wire and is insulated from the core by presspahn and impregnated fabric. The commutator is of ordinary pattern and the brushes are of carbon carried in holders supported from a rocker ring on the frame.

Fig. 12. A caterpillar tractor. Showing the difficult nature of the track. Note baulks under the truck wheels.

The generators are self ventilating and draw in through the machine pits the necessary cooling air from outside the station. In this way the air enters only from below the machine and the openings between the arms of the upper arm-cross are completely closed by covers which extend from the shaft over the stator winding to the frame. In the same manner covers are used over the stator winding on the under side of the generators. These, however, only extend from the stator frame to the inner edge of the rotor rings. By fan blades of sufficient size, larger at the top of the rotor and smaller on the under side of the rotor, the air is drawn into the machine and afterwards forced out past and through all the parts which are to be cooled — the windings and laminations — and when warmed up escapes into the stator frame from which it is free to pass into the machine room. It was possible to use this arrangement partly because the pressure drop in the ventilating system is sufficiently low, and partly because the machine speed and air velocity is not great enough to cause a troublesome amount of noise. The quantity of air for each machine only amounts to about 20 cubic metres per second, so that the machine room can deal with it without becoming too draughty. The covers both above and below are provided with inspection doors. The exciter is separate from the generator as regards ventilation and is self-cooled by the air in the machine room.

Each generator weighs complete about 170 tons, of which the stator weighs approximately 60 tons, the rotor a similar amount, the rest being made up of the arm-crosses, bearings, base ring etc.

Fig. 13. Testing the temporary bridge.

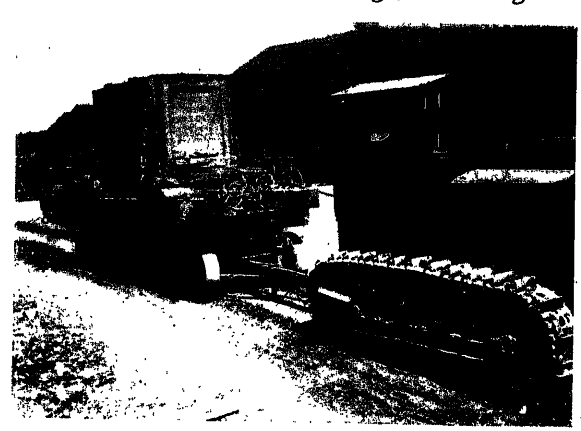


Fig. 14. Transport of heavy parts.

Fig. 15. Aerial view of the power station.

The machines were of course subjected to most careful tests before leaving the shops in order to determine that they met the specified guarantees. All the principal tests were carried out on both generators. On account of the low temperature rise obtained when testing the first generator, it was not considered necessary to carry out more than a simple heating test on the second machine, and accordingly the short circuit test was not carried out for this machine in the same detailed manner. All other tests were made in full for both machines.

In addition to the above tests a runaway test was made on both generators at double normal speed for three minutes. This test was carried out in the specially designed safety pit which is so arranged that the largest rotors can be tested, entirely without risk, even at the highest speeds which may be required. Resistance measurements, and determination of magnetisation and short circuit curves and measurement of losses etc. were carried out in the usual way.

The heat run gave particularly good — indeed what might be considered too good — results, since the measured temperature rises were very considerably lower than the guaranteed value of 50°C for core plates and windings, measured by thermometer or resistance. On account of the position of the power station etc. it is naturally of great importance that the temperature rise on any inaccessible part, measured either by resistance or thermometer, shall not reach any dangerous value. Values made by these methods are often misleading but if a control is taken with suitably placed thermo elements it is possible to determine definitely the heating characteristics in the different parts of the machine. As mentioned above the temperature rise was particularly evenly distributed.

Like the temperature test the efficiency calculations gave exceedingly satisfactory results. In accordance with the American Standardisation Rules, taking the losses of the exciter from the total losses measured, the efficiencies worked out as follows with

		1/1	3/4	1/2 load
for machine No 214604 with cos φ	=1	96.42	95.94	94.75 %
„ „ „ 214605 „ „	„	96.40	95.91	94.62
„ „ „ 214604 „ „	0.8	95.28	94.70	93.25
„ „ „ 214605 „ „	„	95.32	94.74	93.18
The guarant. val. were „ „	1	96.0	95.0	93.5
and „ „	0.8	95.0	94.0	92.5

The voltage rise with constant magnetisation and speed, on throwing off full load amounted on test to 25 % with a power factor of 0.8.

Fig. 16. The stores dump.

Fig. 17. Unloading stores.

Short circuit tests were carried out, during which oscillograph diagrams were taken, and these showed that the momentary short circuit current at no load magnetisation reached about seven times the normal current. The continuous short circuit current with the same magnetisation is 1.25 times the normal.

On completion of the above tests the insulation of the stator winding was tested to iron with 23,000 volts for one minute, and the rotor windings and exciter with 2,200 volts for a similar time. In addition the machines were run for three minutes both with 50 % over voltage and with 50 % above normal current.

The flywheel effect specified, having regard to the speed regulation of the turbines, was to be a minimum of 610,000 kgm^2; actually the value obtained was somewhat higher.

As mentioned in our opening paragraphs the work on the new power station was begun in the early summer of 1923. At the same time the order was placed with Asea for the electrical equipment which, in addition to the generators described above with their exciters and resistances, also included a standby exciter unit, twelve transformers, of which six are divided into two groups — one for each generator — and used in the power station for transforming the generator voltage up to 110,000 volts for transmission to a sub-station in the Porcupine mining district 125 miles away, and the remaining six are installed in this sub-station building, and the whole of the switchgear for the power station, together with various spare material etc. The work throughout was pushed forward with the greatest possible rapidity and the last generator was despatched from the Works about three weeks earlier than was promised in the very cut delivery time, while the remainder of the material included in the Asea order was all finished well within the promised time. How important this was as regards getting the power station set to work can be easily understood when we consider that it lies about 4,500 miles from the factory. In such a long distance it is easy for delays to occur. The power company also pushed on their own part of the work including not only the building of the power station and hydraulic work, but also houses, roads, bridges, etc., together with all transport, so that erection could begin immediately the machines arrived on site. At the beginning of August 1924 the first generator unit was running, and one month later the complete power station was in regular service. Since that time the whole plant has run with exceedingly good results.

PRECISION GEARS.

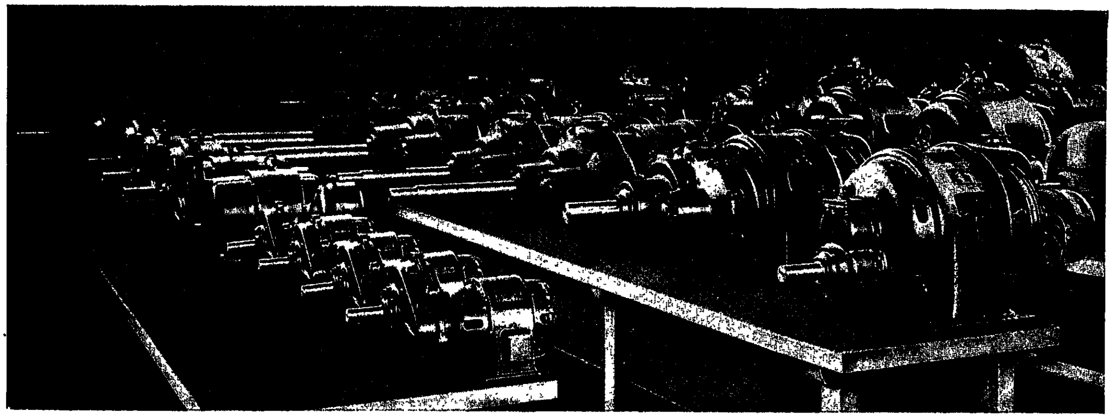


Fig. 1. Some geared motors ready for shipping.

The use of individual or group drive is a question which must be settled in each special case and decided on technical requirements and economic and local conditions, but under all circumstances direct coupling of the motor to the machine or transmission shaft is to be preferred on account of simplicity and reliability. Machine tools and transmission shafts however commonly run at such low speeds in relation to the power they absorb, that direct connected slow-speed motors cannot be considered because of their higher cost, lower efficiency, and, in the case of induction motors, lower power factor, than corresponding higher speed motors. With alternating current supply there may also be the drawback that motors cannot be supplied with a suitable number of poles to give the required speed. A cheaper motor, running at a high speed, is accordingly to be preferred as a rule, and the power transmitted by belt or ropes. Sometimes the total efficiency of an installation is taken into account and consideration may also be given to obtaining the most favourable capital charges for the plant.

The necessity of reliable power transmission with high efficiency for low speeds has become more marked since increased attention has been given to the running costs and capital charges of plant, and since there has been an increasing tendency to make use of direct drives. Reduction gears, which in conjunction with electric motors, have so far only been used in special cases, have now been introduced which fully meet the requirements, great improvements having been made to obtain small losses and silent running.

Asea precision gears for use in combination with standard electric motors are manufactured on the same principles and methods as the well known Stal (Swedish Ljungstrom Turbine Co.) gears for marine work. They are solidly built throughout and are remarkable for particularly high efficiency, silent running, and reliability. Geared motors are accordingly far superior to slow running motors in the electrical respect and are equally good mechani-

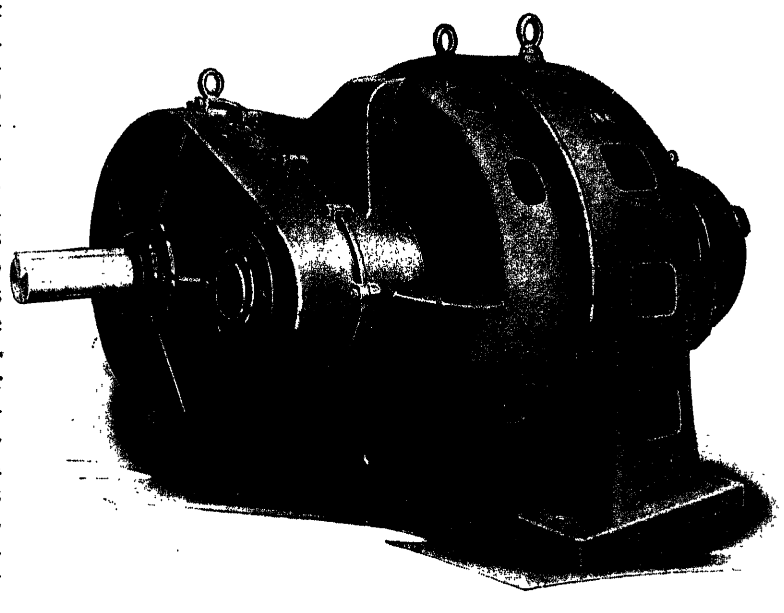


Fig. 2. Autosynchronous motor type M 21, 210 kVA, 750 r.p.m., with reduction gear, type VEV, 750/200 r.p.m.

cally. In comparison with belt or rope drives which in general work with very low efficiency (varying between about 95 and 60 %) their good qualities appear to even greater advantage.

Having regard to the great advantages geared motors permit at speeds as low as may be desired, or within a large range of low speeds — even with a three-phase supply by using variable speed three-phase commutator motors — careful consideration should be given, when selecting a drive, to the question whether such a geared motor would not be the best proposition with respect not only to first cost but also to running costs and reliability.

General Description.

Asea precision gears type VE, VEV, VF and VD are furnished for assembly direct in one unit with endshield pattern motors of horizontal type K 1/4—K 16 and 16 1/2, MK 5—MK 24, M 13—M 23, G 7—G 30, S 3—S 6 and

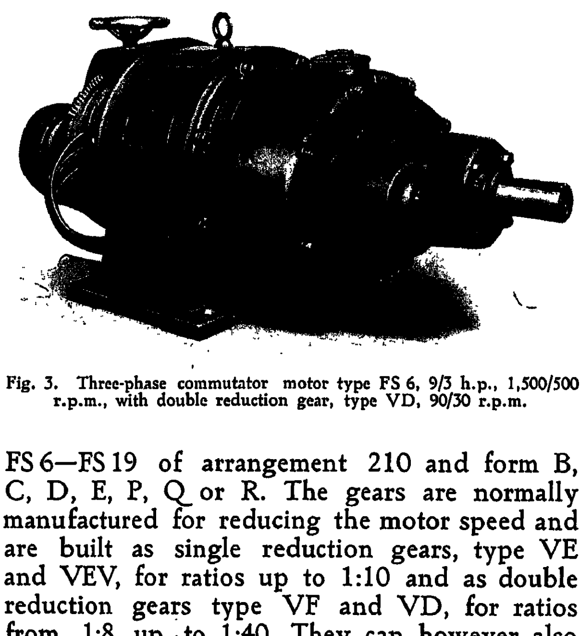


Fig. 3. Three-phase commutator motor type FS 6, 9/3 h.p., 1,500/500 r.p.m., with double reduction gear, type VD, 90/30 r.p.m.

FS 6—FS 19 of arrangement 210 and form B, C, D, E, P, Q or R. The gears are normally manufactured for reducing the motor speed and are built as single reduction gears, type VE and VEV, for ratios up to 1:10 and as double reduction gears type VF and VD, for ratios from 1:8 up to 1:40. They can however also be designed for increasing the speed which is sometimes necessary for driving turbo-ventilators, and certain machine tools, especially where motors are run from low frequency supplies etc., and prices for such special gears will be given on request.

The Gear Casing.

The gears are enclosed in heavy cast iron covers which are either bolted to one end-shield of the motor or cast in one piece with it. The casings are split vertically in types VE, VEV and VF and vertically or horizontally in type VD, and are perfectly oil tight so that they

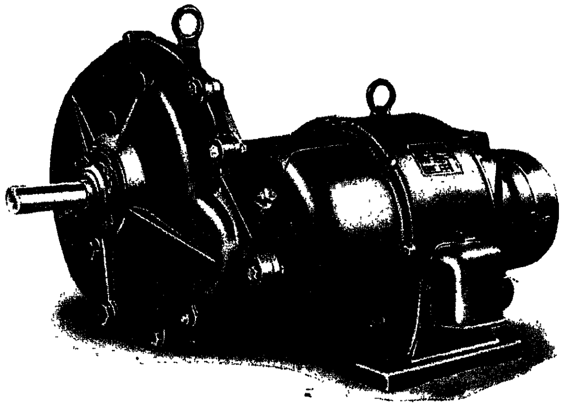


Fig. 4. Induction motor type MK 13, 2.4 h.p., 1,420 r.p.m., with single reduction gear, type VE, 1,420/237 r.p.m.

serve at the same time as oil containers for automatic lubrication. This is carried out by the large gear wheel which throws the oil against suitably arranged screens, which in their turn distribute it to the remaining gear wheels and bearings. All casings are provided with easily accessible oil filling and inspection openings, oil stand-pipes and threaded draw off plugs. Great care has been taken in designing casings and other details to provide for easy dismantling of the gears when necessary.

Gear Wheels and Pinions.

The pinions are tempered chrome-nickel steel and the remaining wheels are made from special tempered carbon steel. For gear wheels of larger diameter however cast iron is used for the centres, and the toothed ring is shrunk upon it and prevented from slipping by special arrangements. The gear wheels, which in order to ensure silent running, have smoothly ground teeth and particularly small pitch are cut in special machines by the precision methods developed by Stal. The errors in pitch which can

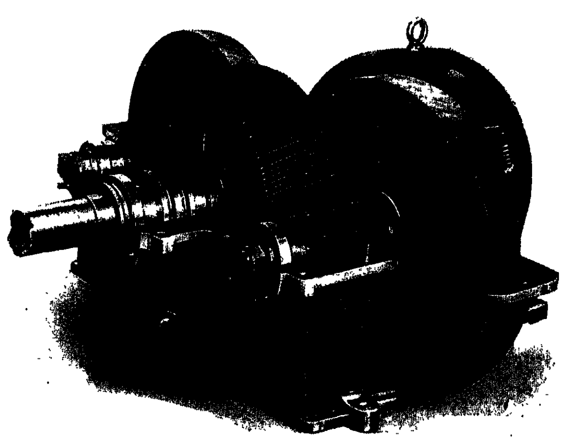


Fig. 5. Double reduction gear type VD, 30 h.p., 1,050/26.25 r.p.m.

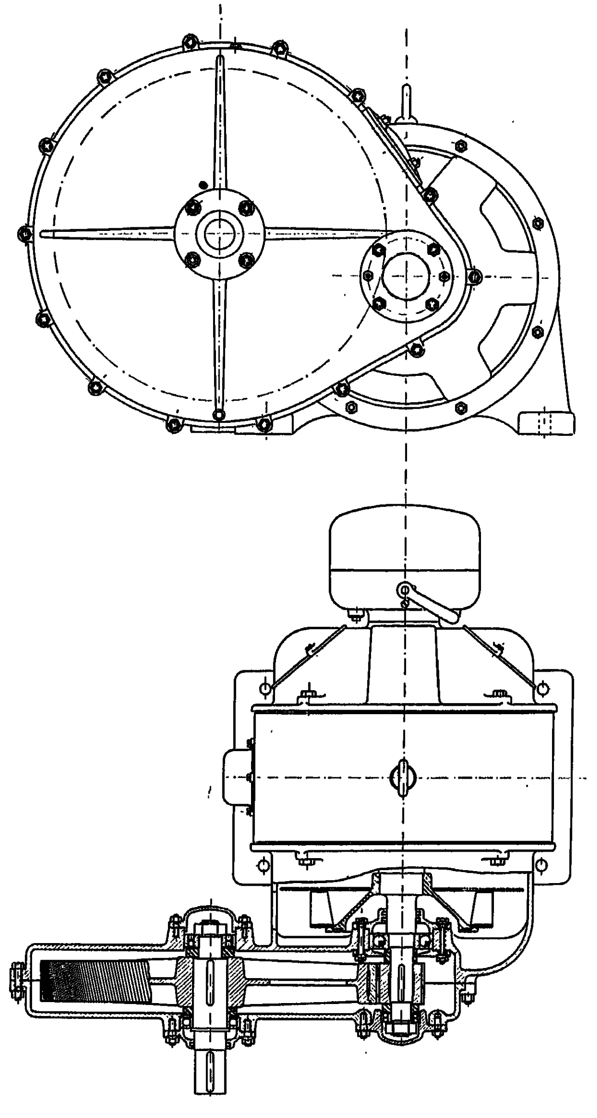


Fig. 6. Single reduction gear assembled with induction motor.

occur by these methods are less than ± 0.0002″, while the profile of the teeth is theoretically correct. By this exact gear cutting unusually high efficiency is obtained, which with single reduction gears reaches 99 % approximately and with double reduction gears about 97.5 % for low outputs and 99 % for large outputs. For the rest the gear wheels and bearings are so well dimensioned and suitably arranged that no special arrangements as regards the pinion and gear wheel are required to take up the shocks which are thrown on them during running, under the conditions of load for which the gears are designed, or to deal with the small strains caused by axial accelerations due to the small errors in pitch mentioned above.

Single Reduction Gears Type VE and VEV.

As fig. 6 shows, both pinion and gear wheel are carried in two ball bearings, of which one is a single row bearing with deep grooves designed to take up any axial stress ocurring in addition to the radial pressure. The secondary gear shaft is always eccentrically placed in relation to the motor shaft and is normally to the left of it, seen from the gear side — left hand arrangement. On request the secondary shaft can be arranged on the opposite side of the motor shaft — right hand arrangement. Gears with the right hand arrangement take longer to deliver as a rule and an additional charge is made.

Double Reduction Gears type VF.

Gears of type VF, which are furnished for lower outputs, have an intermediate shaft and contain four gear wheels. The bearings, as in the case of the foregoing gears are single and double row ball bearings designed for radial and axial pressure. The secondary shaft lies in the same vertical plane as the motor shaft but somewhat above it.

Double Reduction Gears type VD.

Double reduction gears of type VD are furnished for larger outputs and provided with two intermediate shafts, arranged in the same horizontal plane as the motor shaft, and with the secondary shaft concentric with the last named. By this arrangement the least possible number of gear wheels can be used, and consequently the lowest possible friction losses are obtained, while at the same time the pinion on the motor shaft is perfectly symmetrically loaded.

In a double reduction gear having several intermediate shafts it is particularly important to obtain an even distribution of the load on the gear-wheels on the intermediate shafts. In the gears of type VD this is effected automati-

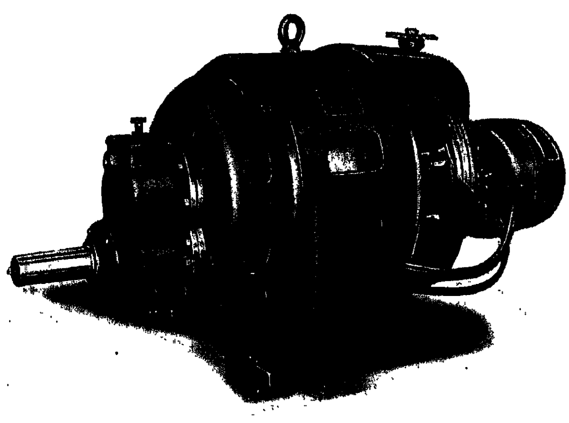


Fig. 7. Three-phase commutator motor type FS 6, 9/3 h.p., 1,500/500 r.p.m., with single reduction gear, type VE, 750/250 r.p.m.

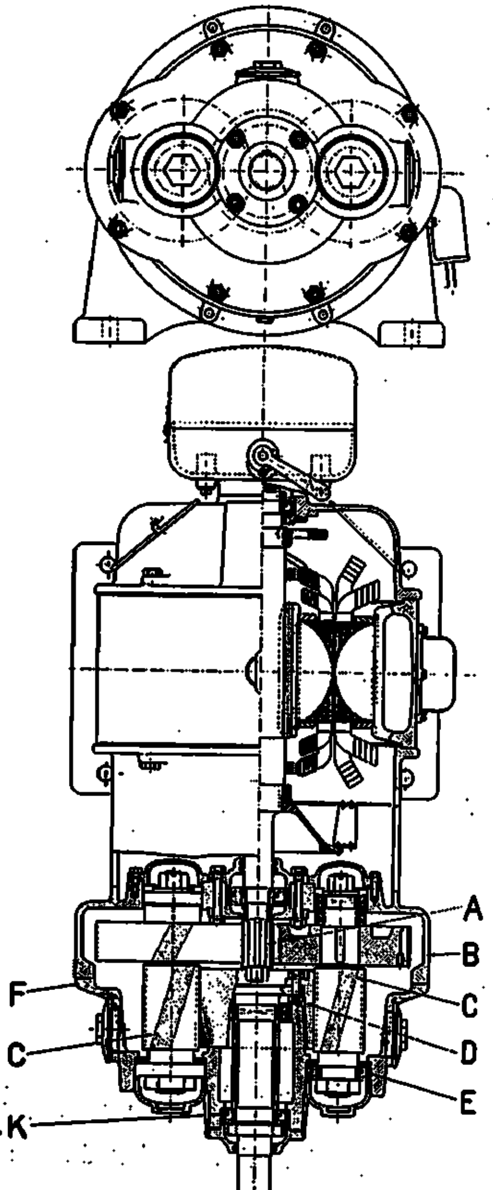


Fig. 8. Double reduction gear type VD assembled with induction motor.

cally in a very simple manner by providing the intermediate shafts with spring axial adjustment. For this purpose the outer ball bearing of the intermediate shafts is of the single row type and is so arranged that it is able to move axially inside a fixed spring bearing housing the springs of which are carefully adjusted so that they are equally loaded. The teeth of the pinion and gear wheel are cut so that they are inclined in the same direction, and a small axial component of tangential stress is obtained. Thus no tendency to axial vibration, due to the inevitable errors in pitch which in the herringhone design causes the load to be thrown alternatively from one half to the other is encountered. The single helical cut gearing does not necessitate special flexible or elastic supports of the wheels in order to compensate for load-variations in the gearing itself. The single row ball bearing takes up this component and transfers it to one or other of the springs. Accordingly if one of the intermediate shafts, due to any slight error in assembly, transmits more than half the total power, the result is that this shaft is displaced to some extent in the axial direction and the greatest inequality in the loading does not exceed 10 %. The maximum stresses in the teeth themselves can accordingly only be 5 % greater than the value estimated for perfectly even load distribution. Lastly it may be mentioned that after the spring housings have been adjusted in the shops the arrangement is locked, so that in the event of the gear being dismantled for any reason it is certain that the same pressure will be obtained on re-assembly.

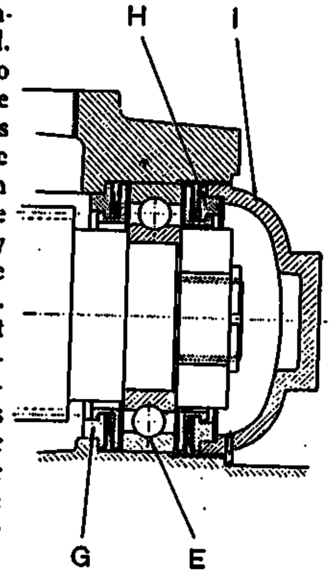


Fig. 9. Spring bearing housing for even load distribution.

The secondary (slow-speed) shaft is carried by one single row and one double row ball bearing.

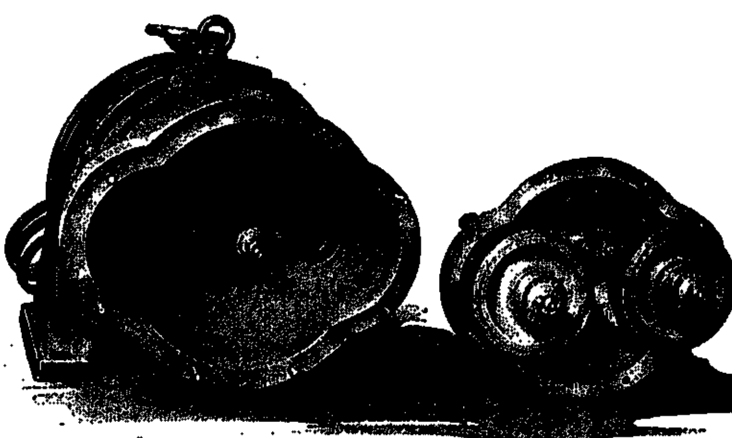


Fig. 10. Three-phase commutator motor type FS 7, 15/5 h.p., 1,500/500 r.p.m., with double reduction gear type VD, 136/45 r.p.m.

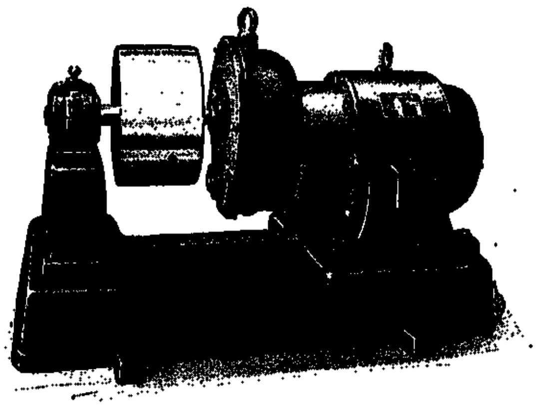


Fig. 11. Induction motor type MK9, Form Q, Arrangement 341, 1 h.p., 1,390 r.p.m., with double reduction gear, type VF 12, 1,390/80 r.p.m.

Direct Coupling and Belt Drive.

All the gears described are arranged for direct connection to the driven machine through a flexible coupling. Suitable flexible couplings are included in our various machine lists.

The gears can, however, also be arranged for belt drive, or for transmitting their power through additional gearing. In this case the free end of the slow speed shaft of the gear must be extended and provided with a special outer bearing. In order to prevent additional stresses in the shaft extension due to bearing-wear the outboard bearing should also, like the bearings in the gear, be a ball bearing. When slide rails are required for belt drive, the motor, together with the gear and the outboard bearing, must be carried upon a common bedplate.

Special geared motors of this design can be quoted for on request if all necessary particulars are supplied.

Oil.

The gear casing must be filled with oil up to the mark set on the oil stand pipe. The oil used should be Mobiloil B Medium, or oil of some other brand having similar properties. The use of thinner or thicker oils and higher oil level than just sufficient for the tops of the teeth to dip about 1/4" deep into the oil lowers the efficiency and prevents the best results being got out of the gear.

Application.

These precision gears are intended for any load which is relatively free from shocks, and for running continuously in the same direction. They are designed to carry the same overloads as the corresponding motors with which they are assembled. They are accordingly suitable for use with most kinds of industrial machines, line shafting etc. When, however, the load is very variable or gives rise to shocks and when reversing service is in question, full particulars should be given and a suitably heavier type employed. For driving reciprocating compressors or pumps the running conditions and the tangential stress diagram must be investigated in each case in order to determine if a geared motor can be employed by using a flywheel on the shaft of the reciprocating machine. It is absolutely impossible to use these gears for drive of machines, where the torque regularly varies from a positive to a negative value.

Precision gears for larger ratios than 1:40 or gears for increasing the motor speed, and designed either for assembly direct with the motor, or for separate mounting and direct coupled to a motor of endshield or pedestal bearing type, will be quoted for on request. Planetary gears also, which are particularly suitable with certain ratios for driving generators from slow running vertical shaft water turbines, or for use between generators and exciters on particularly large slow speed units, will be specially quoted for as cases arise. The planetary gear has, however, a rather lower efficiency than a simple gear, so that the latter is to be recommended when the generator can be erected eccentrically with

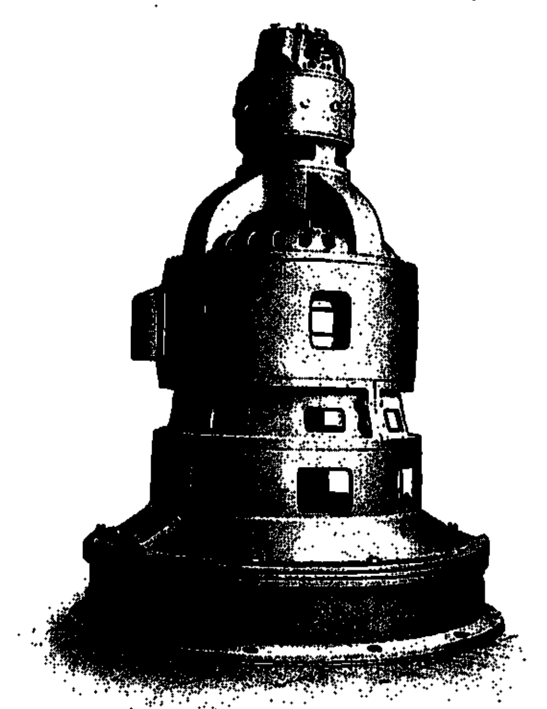


Fig. 12. Three-phase generator type GS 15, 85 kVA, 1,000 r.p.m., with planetary gear 1,000/83 r.p.m.

respect to the driving shaft.

In order to show the approximate extent of the saving which the use of gearing allows, we append the following examples.

An induction motor of from 200 to 300 h.p. at 150 r.p.m. is approximately 33 % more expensive than a high speed motor and gear for the same output. The power factor is also improved about 25 % and the overall effi-

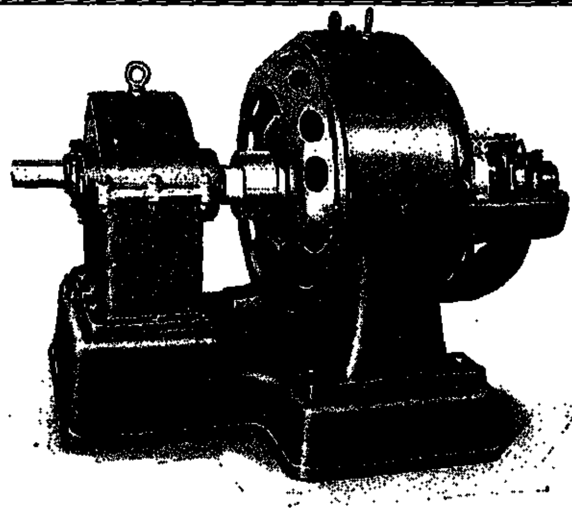


Fig. 13. DC motor type K 16, 200 h.p., 620/800 r.p.m., with separately mounted single reduction gear, 213/275 r.p.m.

ciency is somewhat higher.

An autosynchronous motor of 200 kVA at 200 r.p.m. with exciter is about 25 % more expensive than a geared motor of the same output.

A vertical synchronous generator of 150 to 300 kVA at 83 r.p.m. is about 33 % dearer than a generator with gear for the same output. The efficiency is increased by approximately 2 %.

SWITCHBOARDS FOR PALESTINE AND PORTUGAL.

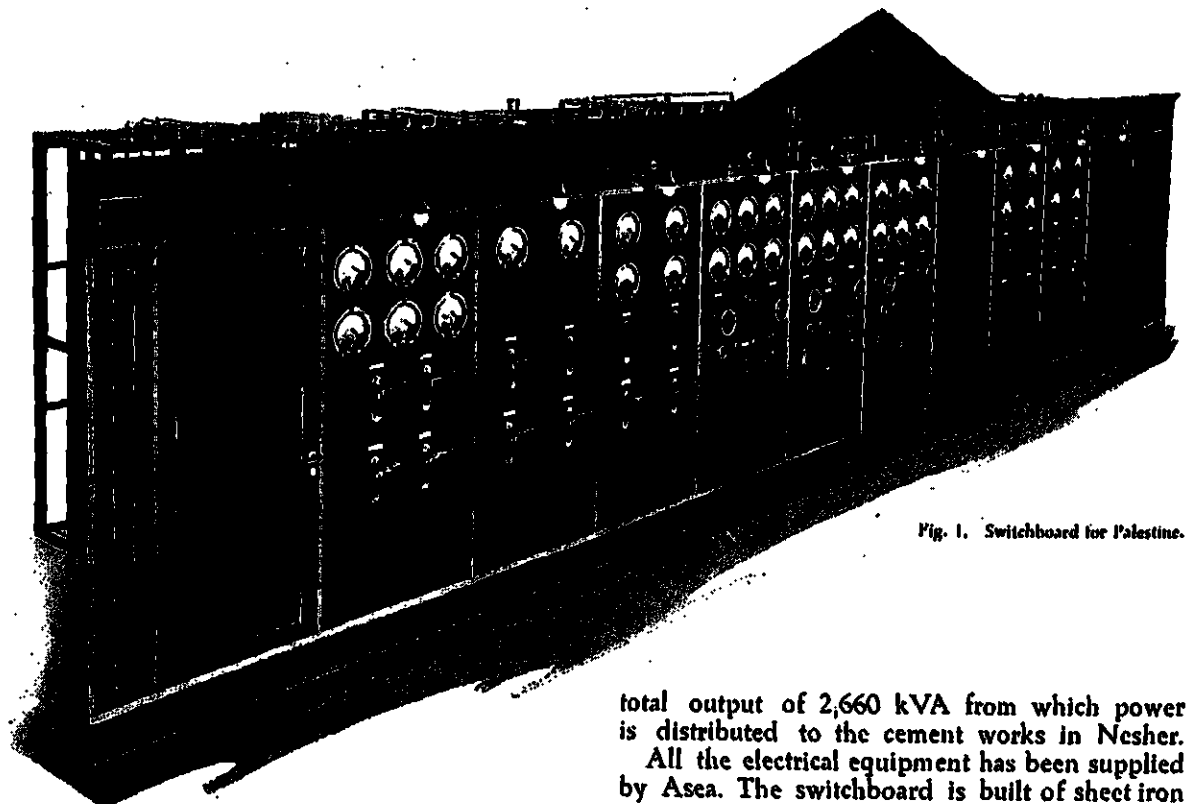


Fig. 1. Switchboard for Palestine.

Fig. 1 shows one of Asea's switchboards delivered to "The Portland Cement Co. Nesher Ltd" in Palestine. The switchboard is installed to control a generating and distributing station in Nesher, an industrial centre approximately eight kilometers from the harbour of Haifa. This plant consists of three generator units with a total output of 2,660 kVA from which power is distributed to the cement works in Nesher.

All the electrical equipment has been supplied by Asea. The switchboard is built of sheet iron in accordance with our standard design E. The switchgear behind the board is divided into two sections with an inspection gangway between them. The busbars are located over the inspection gangway to facilitate connection to the two sections.

The generator panels are grouped in the centre of the switchboard and there are three distribution panels at each end.

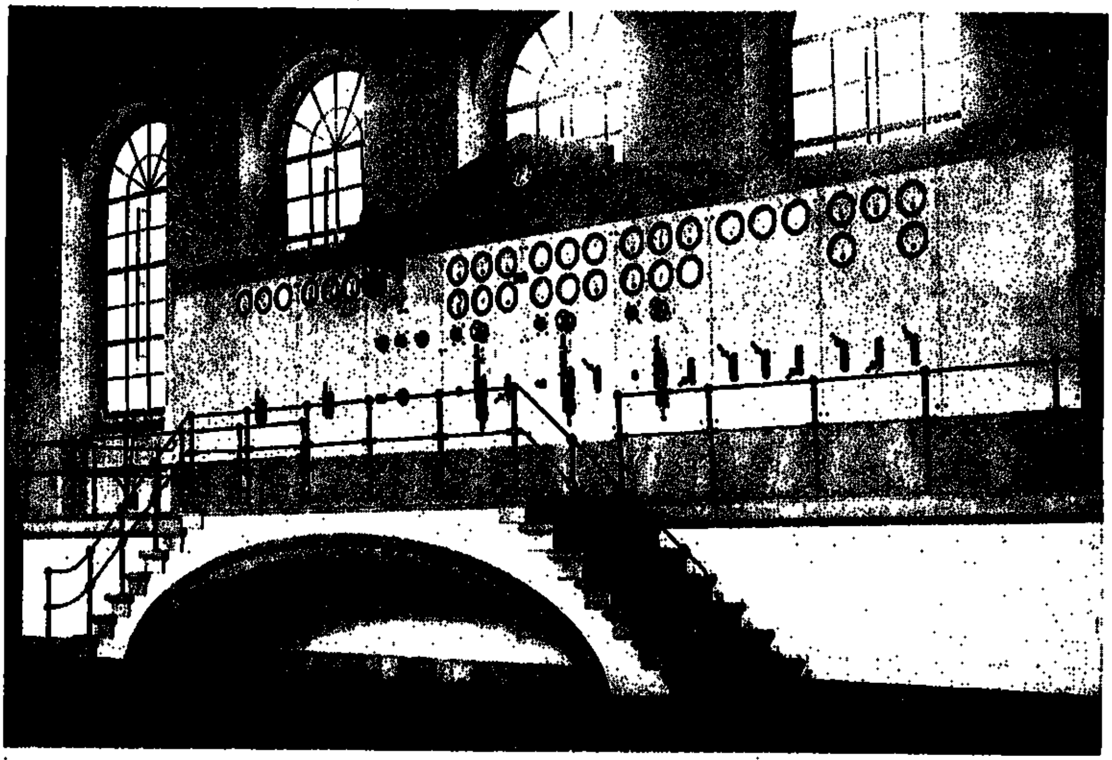
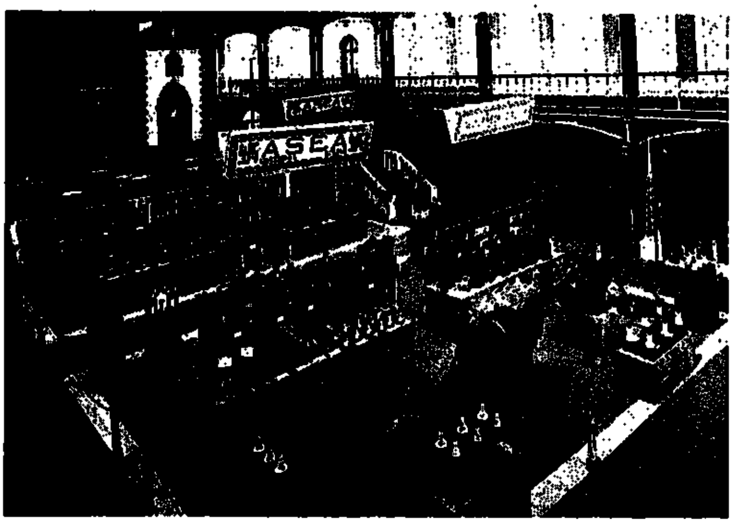


Fig. 2. Switchboard for Portugal.

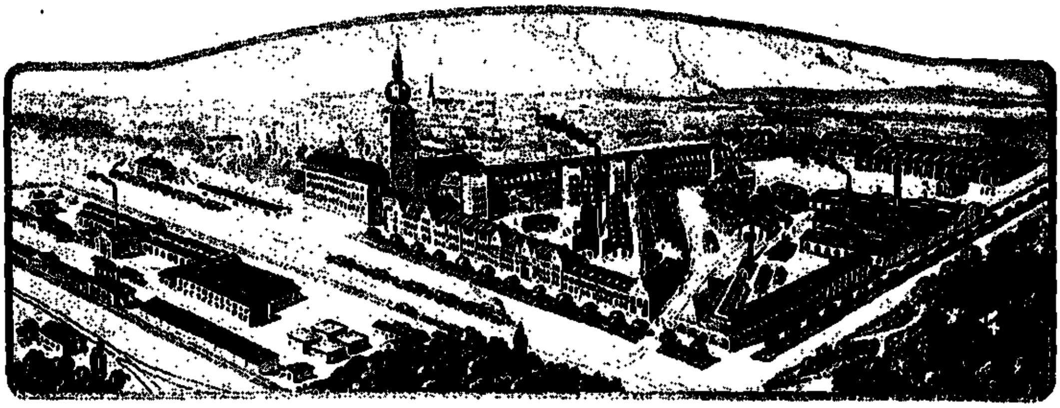
Fig. 2 shows a switchboard built by Asea for a generating and distribution station in Lisbon, containing two generators type G 183 and one type G 205 with a total output of 1,750 kVA at 400 volts. This station is to supply power to the largest and most modern mill and bakery of its kind in the Iberian Peninsula.

This switchboard is in accordance with our standard design D of white Italian marble with sill and cornices of green marble. As will be seen from the photograph, the switchboard consists of three generator panels, four distribution panels, one synchronizing panel and two spare panels for future feeders.

This order was handled by Messrs. Jayme da Costa L:tda., our representative in Portugal.



The figure shows an interior from The Electrical Exhibition at Oporto in 1924 at which Asea's representatives in Portugal, Messrs. Jayme da Costa L:tda., had arranged a comprehensive and very successful exhibition of the Asea-manufacture.



Asea's head office and works in Vesteras, Sweden.

Vesteras 1925, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

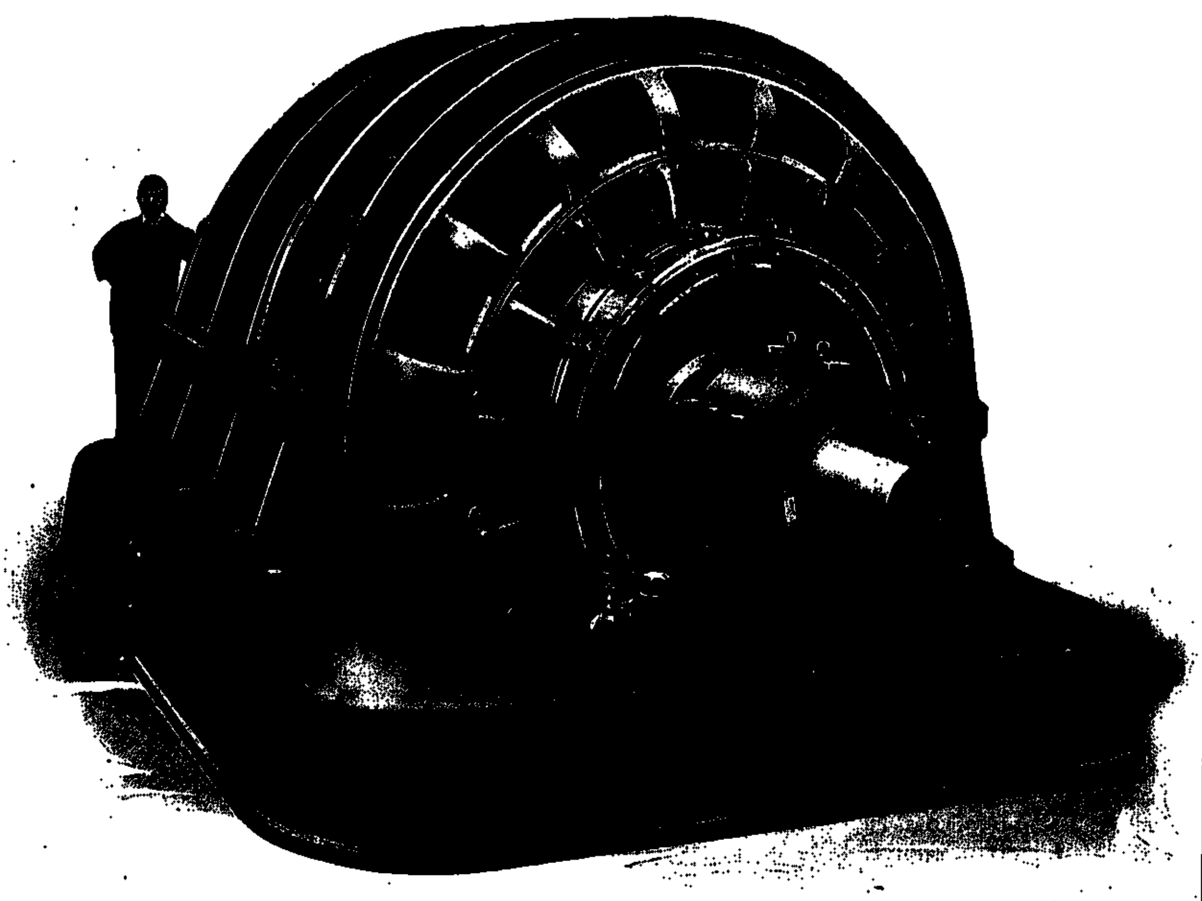
ALLMÄNNA SVENSKA
ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5. CHANCERY LANE—LONDON

VOL. II
1925

All correspondence should be addressed to the Editor. Publicity Dept.
Asea, Vesteras, Sweden.

JULY-SEPT.
Nos. 7-9



Double continuous current motor of 9,200 h.p., 1,200 volts, for Domnarvet Rolling Mill, Sweden.

ELECTRICALLY DRIVEN ROLLING MILLS.

The use of electric motors for driving rolling mills is now so general that when laying down new mills, or modernising those already in existance, the use of any other motive power rarely receives consideration. Side by side with the demand for electric motors for rolling mill drives there has grown an insistance on increased capabilities; and it can safely be said that the electric motor has met all demands made upon it in a satisfactory way, both as regards reliability, and adaptability to varying conditions. In Sweden this question of adaptability has, without doubt, made the electric motor more indispensible for rolling mills than in other countries. The Swedish iron industry since early times has been justly celebrated for articles of special quality, and the rolling mills are not, in general, intended for what is commonly known as mass production, but are intended to handle smaller quantities of material, often of widely varying character.

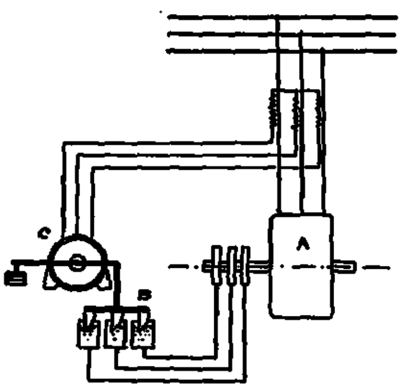


Fig. 1.

This means that the rolling mills must be flexible, *i. e.* they must be able to handle work of any quality and dimensions required at the time. This influences the selection of the driving motor to a great degree as the motor must be adaptable as regards output and speed to suit any desired rolling program.

Ever since 1894, when the first electric rolling mill motor was installed in Sweden, rolling mill motors for the Swedish iron works have been made, with few exceptions, for AC supply. This is also a point of difference from other countries where DC has come much more into use.

The early and far reaching electrification of Sweden has however been based on the utilisation of the many existing waterfalls, so that the generation of electricity is concentrated at hydro-electric power stations, which have naturally been furnished for the distribution of power in the form of AC over wide areas for consumption. The Swedish ironworks, accordingly, have only AC available as a rule, and a substation for converting to DC has in general not been taken in hand on account of the cost. In countries such as England, Belgium, France, and Germany, the ironworks are concentrated at the coalfields, and usually have their own large blastfurnace installations from which blastfurnace, gas is obtained, as it were, gratis and used for running gas engine or steam turbine driven power stations the supply being in this case wholly or partially DC, as found most suitable.

One reason which has contributed to the general adoption of AC motors in Swedish rolling mills, in spite of the requirements as regards variable speed, is that simple means were discovered at a very early date for obtaining such variable speed even with AC machines. The methods which came into use as long ago as 1899 were based on K. A. Lindstroms and R. Dahlanders pole changing device and on E. Danielssons tandem connection. These same methods are still employed although to a reduced extent on machines for new installations supplied by Asea.

The general use of AC motors can also be

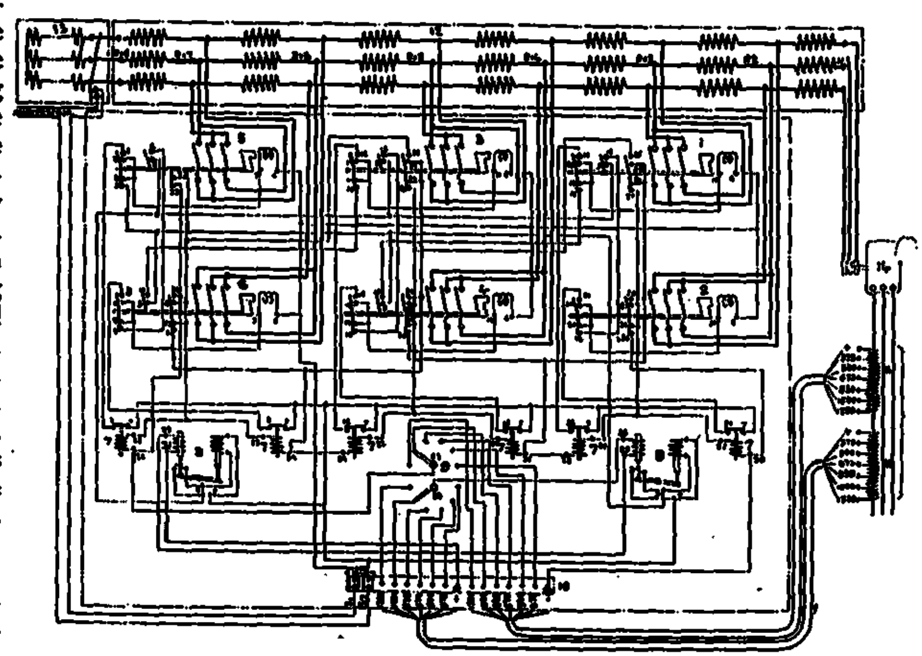


Fig. 2.

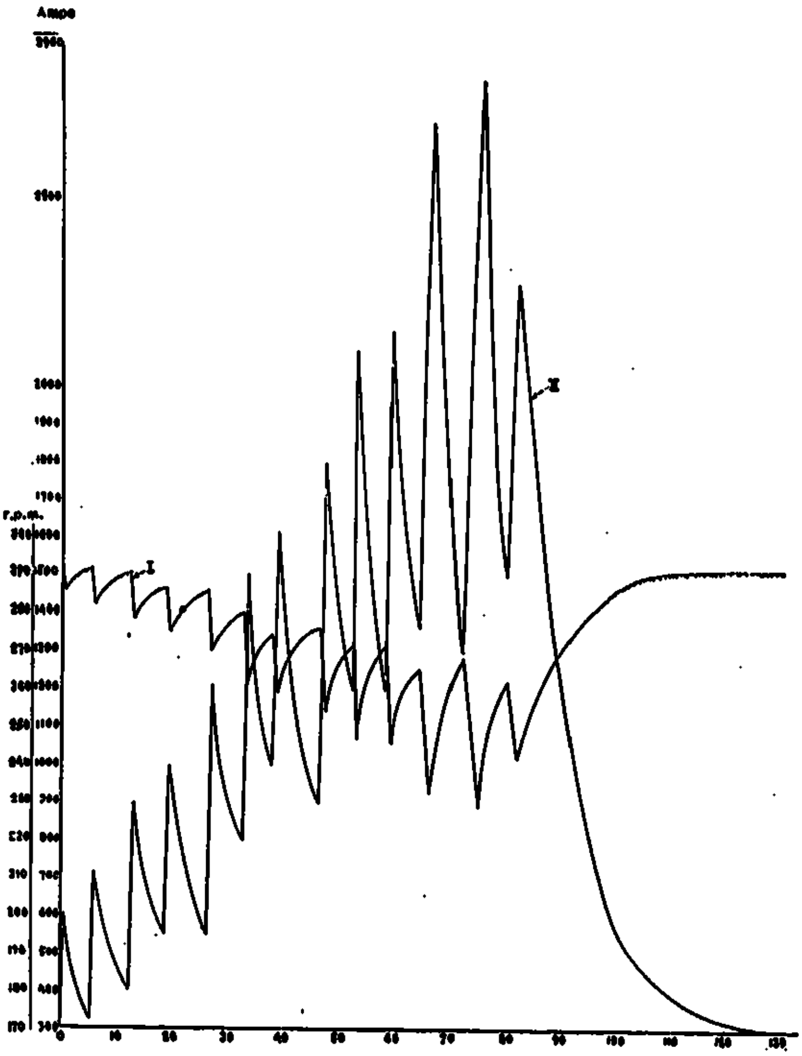


Fig. 3.

to be rolled, more particularly for Plate Mills, Wire Mills, etc.

At the same time these motors are used to a large extent for breaking down rolls were the billets are afterwards passed through separate finishing rolls.

As the roll speeds in a number of cases are lower than those for which induction motors can be economically built, the power is usually transmitted to the roll shafts by some kind of reducing gear or rope drive. Rope drive is the most usual. For wire mills and light work in general, the rolling speeds are so high (up to 500 r.p.m.) that induction motors can with advantage be direct coupled. A common arrangement is for the finishing rolls to be direct coupled to the motor and to drive the roughing rolls through reducing gear.

On account of the nature of rolling mill work the equipments are practically without exception constructed with flywheels which enable the motors to be of a more economical size, being designed to deal with the average power requirements only. The work done by the mill is derived from the motor and flywheel continuously working in conjunction with one another.

To enable the energy stored in the flywheel at any speed to be made use of, it is necessary for the speed to be reduced. As the flywheel effect (or energy of rotation) is proportional to the square of the speed in accordance with the well-known formula, $\frac{1}{2}mv^2$, the work obtainable from the flywheel by reducing its speed is proportional to the difference of the squares of the highest and lowest speeds. Accordingly if the peripheral speed of the flywheel is reduced from v_1 to v_2 and the weight of the flywheel concentrated at the periphery is m, the power recovered is $\frac{1}{2}m\,(v_1^2-v_2^2)$. If the speed is reduced for example 10 %, the amount of power recovered is no less than 19 % of the total energy of rotation of the flywheel. As however the slip of an ordin-

ascribed to the fact that in comparison with DC motors the construction is more simple and this is a great advantage in rolling mill work.

A number of the arrangements more commonly in use are considered below, and several typical Asea installations are described.

Electric rolling mill motors can be suitably divided into two main groups:

1. Single speed motors.
2. Variable speed motors.

I. *Single Speed Motors.*

The motors in this group are almost without exception ordinary induction motors. These were the first machines used for electric rolling mill drives, and even to-day represent the best practice for the work where variable speed is not required by the rolling program. Mills for which these motors are suitable are in general those where one quality or size of product only is

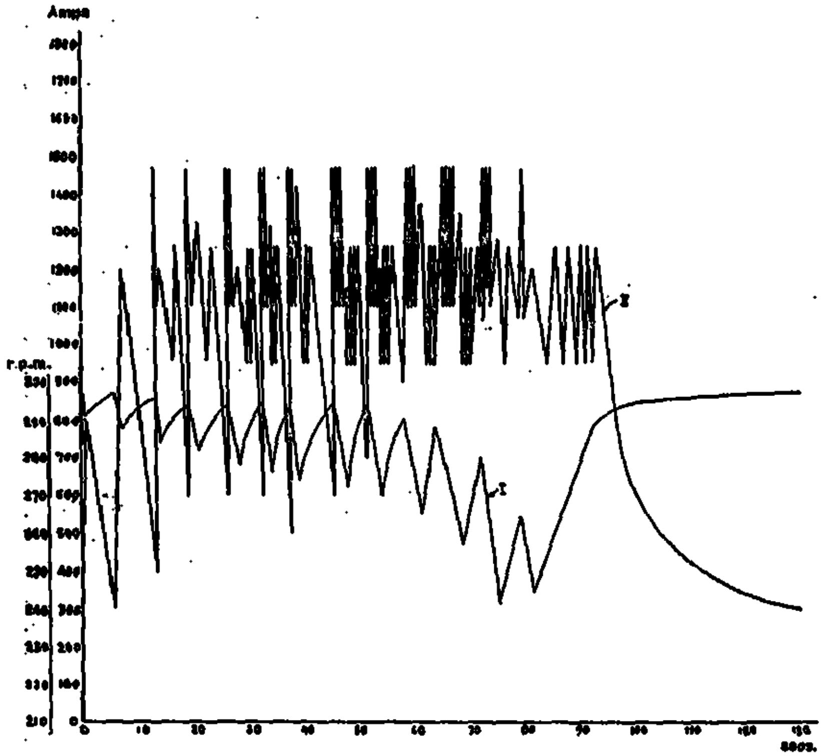


Fig. 4.

sistance with movable electrodes counter-balanced by a lever with counter weight and actuated by the induction regulator C, which is electrically connected to the rolling mill motor's primary circuit by a current transformer. This method has been largely used in conjunction with the well-known Leonard-Ilgner system, and can in general be said to be suitable for such work when the load variations are relatively slow. If the load variations are rapid, the method is much less satisfactory. On account of the relatively large masses which have to be moved, the whole system works somewhat sluggishly, so that difficulty arises in making it act sufficiently fast to keep up with a rapidly fluctuating load, and as a consequence overshooting and hunting take place.

Another method which fulfils the difficult requirements of quick regulation is the so-called relay method where relays effect the automatic variation of the resistance.

ary induction motor with increasing load is inconsiderable, only a very small part of the energy of a flywheel coupled to it can be utilised to relieve the load on the motor, and consequently the load on the power supply. On this account induction motors for rolling mill work are generally furnished with extra rotor resistance so that a bigger speed drop is obtained with increasing load, and a larger proportion of the flywheel energy is recovered during the periodic overloads occurring during rolling. The load on the supply by this method, however, *i. e.* with a constant slip resistance, must always be very unsteady, although quite satisfactory in many cases. If however it is necessary to keep down the maximum demand, or if it is desirable to keep the power fluctuations between certain limits, the slip resistance should be furnished with a regulating device of some kind which enables the resistance to be altered during the rolling in proportion to the load taken at each instant. As it would be far too troublesome to attend to this regulation by hand, some kind of automatic regulator is used to give the variation in resistance required. The best known of the various methods is that making use of a liquid resistance and induction regulating device. The working principle of this method of regulation is shown in fig. 1 where A is the rolling mill motor, B the liquid re-

Asea has recently furnished automatic slip regulators on the last named principle to two Swedish rolling mills. One of these installations belonging to the Avesta Iron Works has been in use for some time, and as the installation is of interest from several points of view, a short description of it will be given.

The rolling mill in question consists of two plate mills for rolling heavy boiler plates, ship plates, etc. The rolling mills are exceedingly heavy for their size. The roughing rolls weigh 22 tons each. Both mills are constructed on the three high system with three parallel smooth rolls of which the middle one is adjustable. The mills are designed for a yearly production of about 30,000 tons of finished rolled plate, and for producing plates weighing between 450 and 4,000 kgs. The power for driving the mill is obtained from a 500 h.p. water turbine, having a speed of 65 r.p.m., direct coupled to the rolls, and from a three-phase Asea induction motor of 800 h.p. with a synchronous speed of 300 r.p.m., 500 volts, 50 cycles. This last drives through ropes on to a large rope wheel mounted together with a flywheel on the extended shaft of the rolling mill. The diameter of this wheel is 9 metres, and the combined flywheel effect is $GD^2 = 3,000,000$ kgm².

On account of the nature of plate rolling, the peaks during the first passes are of exceedingly short duration. When designing the electrical equipment, the problem arose, how to arrange automatic slip regulation so as to obtain the maximum possible benefit from the flywheel and to limit the power taken from the supply to a value corresponding to the mean power required during every rolling program. It was immediately obvious that the result with the older method using an induction regulator and liquid resistance could not be expected to be satisfactory. On this account Asea decided to introduce the relay method.

As it would take too large an amount of space to describe in detail the regulator supplied by Asea in accordance with this principle, we refer to fig. 2 which clearly shows the chief details of the arrangement. The principal parts of the apparatus are denoted in the figure as follows:

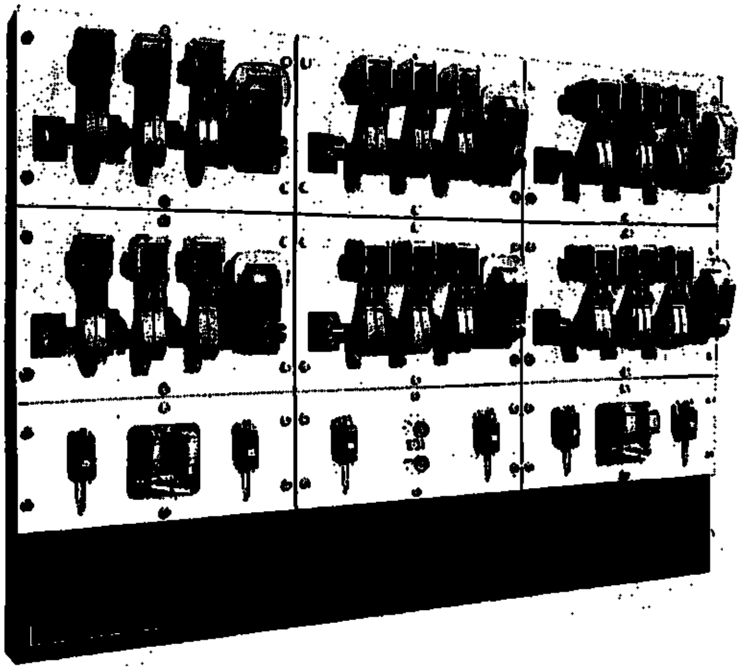


Fig. 5. Relay panels for automatic slip regulation at Avesta Iron Works, Sweden.

1, 2, 3, 4, 5, and 6 are six contactors arranged to short circuit in turn the divisions of the regulating resistance 12 which is connected in the rotor circuit of the motor.

7 denotes the 6 overload relays.

8 denotes 2 current limit relays.

9 is a tapping changing switch for obtaining different ratios on the current transformer 11.

13 is the motor starter, and 14 the rolling mill motor.

As stated above the arrangement is designed to keep the power taken from the supply within certain limits. At a predetermined minimum value of the current the current limiting relays (8) operate successively completing the operating circuit of the solenoid switches which short circuit the resistance and reduce the motor slip. During these periods the motor accelerates, storing up energy in the flywheel. At a predetermined maximum current the maximum relays (7) come in their turn into operation, breaking the operation circuit of the short circuiting switch, and thus introducing resistance and increasing the slip. During such periods the motor slows down and energy is returned from the flywheel. Both maximum and current limiting relays are excited by their own current transformers (11) which are provided with a number of tappings corresponding to a number of different current values (mean values) for which the arrangement is designed to regulate. Setting for different currents is effected by the multiple contact switch (9).

This arrangement has been in use for some time and has operated in a perfectly satisfactory manner.

Figs 3 and 4 show the calculated power demand both with permanent slip resistance and with automatic regulation as described above. The advantages of the last are apparent from the curves.

Among other methods which have been tried, or at least discussed for automatic slip regulation, can be mentioned a method which depends for its action upon speed variation. The automatic regulator can in this case be entirely mechanical, *i.e.* a speed regulator which acts directly on the slip rheostat in such a way that more resistance is connected in circuit as the speed falls, and is short circuited as the speed increases.

As mentioned above the function of an automatic slip regulator is to limit the power demand on the system to an amount corresponding to the mean value. No arrangement for keeping this demand quite constant can be realised in practice. Thus it is obvious, for example, that if there should be a pause in the rolling, the demand must sink to the no load value.

Apart from the more effective smoothing out of the power curve which can be obtained by automatic slip regulation compared with what is obtainable with fixed slip resistance, the automatic device has other practical advantages. Thus the motor is used to better advantage, the

no load speed is higher, and the maximum speed drop lower, from which it follows that the retardation and accceleration periods are shorter and that the time for the pass and the time between passes is shorter. The automatic regulator consequently makes increased production possible. If this possibility is not taken advantage of for any reason the size of the flywheel can be reduced as an alternative, or the size of the motor and its maximum torque can be reduced.

With any kind of automatic slip regulation it is necessary to see that the flywheel is sufficiently large to enable the amount of the slip to be kept within reasonable limits, preferably not exceeding 15—20 %.

It must not be forgotten that when the slip of an induction motor is increased by introducing rotor resistance, a loss is introduced which is at each instant nearly directly proportional to the magnitude of the slip. Assuming for

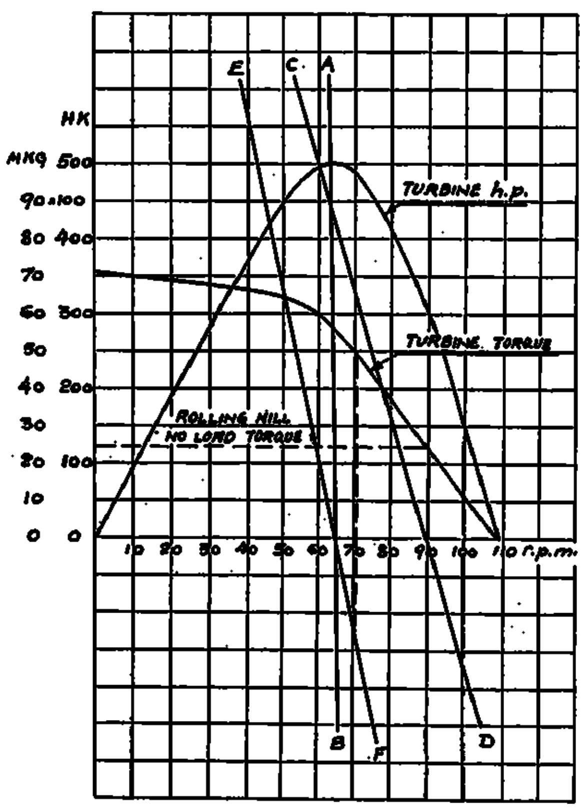


Fig. 6.

example that a rolling mill motor furnishes an average of 1,000 h.p. during a rolling process, and that it is furnished with a rotor resistance which at this output causes a slip of 10 %, then 100 h.p. is continuously wasted in the resistance. It follows from this that the efficiency of an induction motor furnished with a slip resistance is never favourable by comparison with that of other types of motor and other systems, in spite of the fact that the motor running alone may work with an exceedingly good efficiency. In this connection it should however be carefully observed that the average losses due to the slip resistance are dependent on the *average* output of the motor during rolling. It accordingly follows that the average loss in the resistance of a motor designed for a maximum slip of 10 % is certainly not as great as 10 %.

Considered with regard to the maximum slip and load respectively, the average loss in the resistance is on the contrary very small.

Apart from the automatic regulation of the slip the installation considered above is of interest from the point of view of the parallel loading of a water turbine and electric motor. The combination of a water turbine and motor for driving a rolling mill is by no means new, and this arrangement has been used in many installations in Sweden. The combination has arisen naturally enough in cases where a water turbine has been used in the first instance for the drive, but has been of insufficient size to deal with later extensions to the mill. Driving of rolling mills by water turbines has always been common in Sweden, but during the last few years these drives have been more and more displaced by electric motors, as mills have been brought up to date, their size increased, and iron works electrified throughout. In water turbine driven mills where an increase in the power has been found necessary, and where the water power cannot be suitably used for some other purpose, in most cases an electric motor has been installed as an addition to the turbine. Naturally in such cases it is desirable that the turbine should run as far as possible fully loaded, and that the electric motor should deal with the extra power which the turbine is unable to supply.

For such parallel running of a turbine and motor a number of careful measurements must be made beforehand. To prevent dangerous overloads on the motor, the turbine should run with as big a margin of power as possible so that at the speeds normally occurring it does not work up to its full capacity. Further the motor should have a suitable slip so that the flywheel effect can be used over the peaks. The parallel drive can be most easily studied by reference to the curves in fig. 6 which show the torque of turbine and motor in relation to the turbine speed.

The power of a water turbine as a function of its speed can be represented, it is known,

by a curve which approximates to a parabola, and in this case the curves of power and torque are much as shown in the figure. Without introducing great errors the torque of the motor can, up to a certain maximum, be taken to vary as a straight line.

Assuming now that in accordance with fig. 6 a turbine with a speed of 65 r.p.m. gives 100 % torque, or about 5,500 mkg, and that the motor with approximately the same *relative* speed gives 160 % of the turbine torque or about 9,000 mkg (this relation between turbine and motor torque is that obtaining for the installation in question), then an increase in the load certainly causes the torque given by the turbine to increase above the 100 %, but only to a very small extent while the motor's torque is very greatly increased. All increases in the load torque above the normal torque of the turbine are consequently for the most part thrown on the motor. This is the case to the greatest extent when the motor works with small slip as shown by curve A—B. Accordingly if the motor is allowed to run with a larger slip, e.g. as shown by curve C—D, it is spared to some extent, as the rotating masses can give up a certain amount of energy. If there is a cessation in the rolling, *i.e.* if the driving machinery runs at no load, which we can assume to require for example 45 % of the normal torque of the turbine, then the turbine tries to increase its speed up to 90 r.p.m. With a motor whose torque curve coincides with C—D the speed also tends to increase to this value unless prevented by the governor, and the turbine deals with the no load requirements alone, the motor's torque being zero and its speed that of synchronism.

With a motor running according to curve A—B, as synchronism is reached at 65 r.p.m., the turbine speed never rises to such a high value, since the motor when run above synchronism begins to absorb mechanical energy and to act as a generator. The load on the turbine is consequently increased above the no load value, and its speed rises to a value at which the power developed by the turbine is equal to the load absorbed by the rolling mill and the motor. The power delivered by the motor running as an asynchronous generator is equal to the power developed by the turbine decreased by the power required to run the rolling mill at no load and by the losses in the motor. From the above it follows that by using a combination of motor and turbine, power can be returned to the network during the rolling mill's no load period, and at the same time the turbine can be practically fully loaded during the whole process.

If the motor is small compared with the turbine and has a large permanent slip resistance, it is an advantage to have the motor's synchronous speed near to the runaway speed on the turbine, as by this means dangerous overspeeds during no load periods are avoided.

It should be noted that the above remarks have not taken into account the presence of a turbine governor. By using a suitable motor, however, the advantages of such a governor are very small. In many cases it may even be a disadvantage to make use of one. Turbine governors are not accordingly used with the rolling mills under consideration.

It should be evident from the above that it is an advantage to use automatic slip regulation where a turbine and motor are running in conjunction. Suppose for example that curve A—B is the torque characteristic for a motor with short circuited rotor, and curve E—F that with the greatest amount of slip resistance connected, then automatic regulation can be said to give rise to a rotation of the torque characteristic about the point 65 r.p.m. and between the extreme positions A—B and E—F in proportion to the load, so that for a certain maximum load we obtain the position E—F, and for a certain minimum load the position A—B. Between certain maximum and minimum values of the load the motor contributes approximately constant power, while during the no load periods the rotor is automatically short circuited so that dangerous over-speeds are avoided, and at the same time the amount of power returned to the supply by the motor is the largest possible.

By a suitable selection of motor and turbine with regard to speed and output, it is possible to obtain parallel running which is almost ideal.

It has been assumed above that the turbine runs with full flow of water continuously and with full gate. Accordingly if the water begins to fail, as may often be the case, the motor cannot be protected against overload, if the rolling program is continued as before. In cases where a lack of water is expected periodically, there is no possible course except to design the motor with large overload capacity. In this connection also it may be of assistance to point out that when there is a lack of water, it can easily happen that the turbine actually imposes a load on the motor which in addition to its other work has to run the turbine "backwards" *i.e.* above its natural speed.

As stated before, AC motors are used in overwhelming majority for driving Swedish rolling mills.

With the developments which have now taken

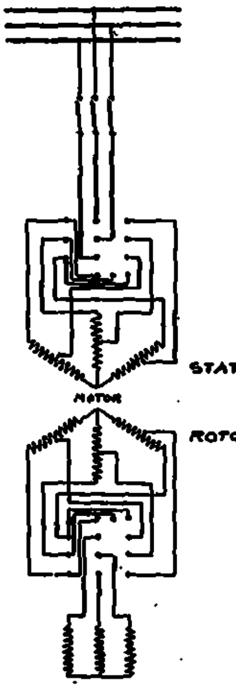


Fig. 7. 2-speed motor, Lindstrom—Dahlander pole changing method.

place in electrical machine design, there no longer need be any hesitation about installing DC motors wherever they seem to offer advantages, even though AC motors are still unsurpassed as regards reliable operation.

II. *Motors with variable speed.*

From the point of view of speed variation these motors can be divided into two main groups, viz.:

A. Multi-speed motors.

B. Motors with speed regulation.

A. *Multi-speed motors.*

To this group belong AC motors with pole changing devices, and tandem motors.

As previously mentioned, motors of this kind have been very widely used for rolling mill drives, and in general can be said to be suitable for such work when the product is determined at the outset, and where variations in quality and dimensions are few. As the speed of an induction motor, at any given periodicity, is inversely proportional to the number of poles, these special machines can only have one speed corresponding to each number of poles obtainable by different combinations of the winding. If only two speeds are required, these can be obtained by three different methods, viz:

1. Lindstrom—Dahlanders pole-changing device.

2. By separate motor windings, and

3. By tandem connection (Danielsons patent).

1. *Lindstrom—Dahlanders Pole-changing Device.*

This arrangement is most suitable where the two synchronous speeds are in the ratio of 1 to 2. The motor is wound exactly like a standard machine, but the connections between the coils are so arranged that by a simple change-over switch the number of poles can be altered in the ratio of 2 to 1. A two-speed motor of this type develops the same torque at both speeds, *i. e.* its output at the higher speed is double the output at the lower speed. Fig. 7 shows the diagram of connections for this method.

2. *Motors with two Separate Windings.*

These are used where the two speeds are not in the ratio of 1 to 2, but lie nearer to one another. Fig. 9 shows a diagram of connections for this method, which as a general rule is suitable for use where the voltage is low. If the two speeds are in such a ratio that a corresponding number of poles cannot be suitably obtained, and if the voltage is high, the third method is used, viz.:

3. *Motors in Tandem in accordance with Danielsons Patent.*

This consists of two separate motors mounted upon a common shaft of which one, the main motor, is connected to the supply and the other, the secondary motor, is connected in the rotor circuit of the first. Of the two speeds the higher is obtained by running the main motor alone (as an ordinary single speed induction motor) and the lower by tandem coupling the motors as described above, when the sum of the number of poles of the two motors determines the speed. The secondary motor can be constructed as a squirrel cage machine.

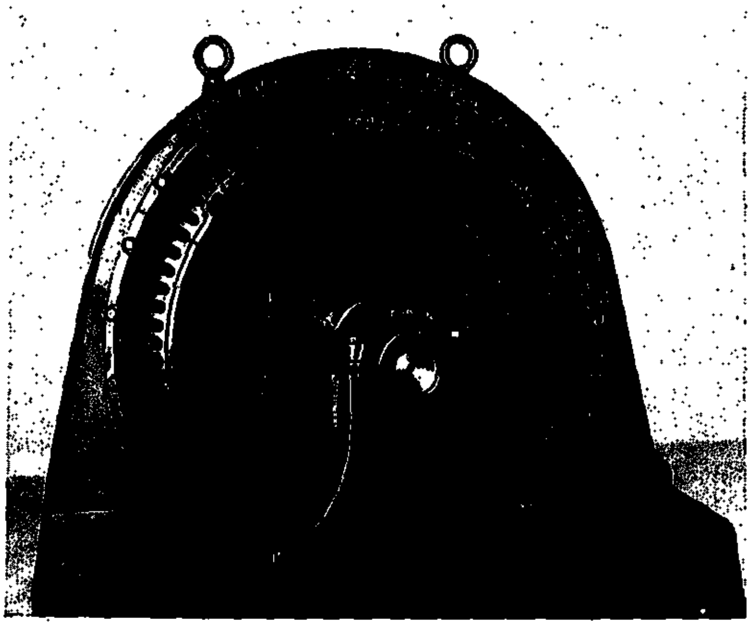


Fig. 8. Asea three-phase 2-speed motor, 800 h.p., 500/375 r.p.m., 800 volts, 50 cycles, for wire mill at Hellefors Bruk.

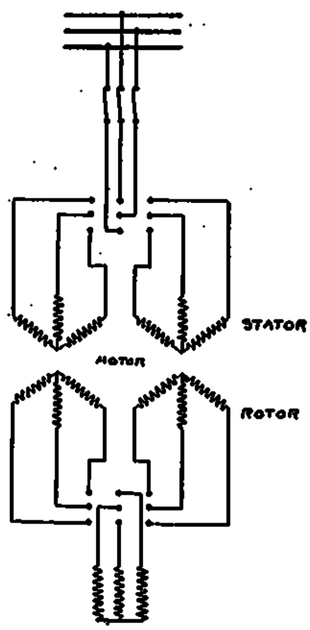


Fig. 9. 2-speed motor having 2 separate windings.

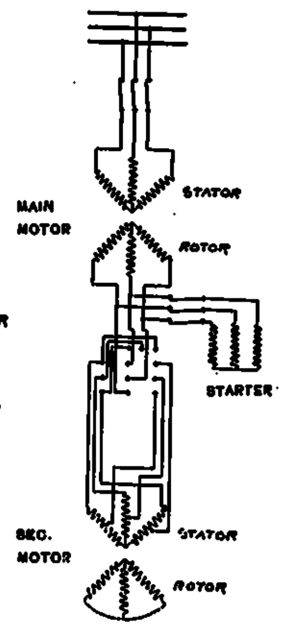


Fig. 10. 3-speed tandem motor.

If several speeds are required, tandem coupling can also be used. Thus, three speeds can be obtained by constructing the secondary motor as a two-speed motor. By other similar combinations of the above methods it is possible to obtain up to six different speeds. Figs. 10 and 14 show two coupling diagrams for tandem motors in accordance with this principle.

In comparison with single-speed induction motors multi-speed motors built in accordance with the above principles have somewhat poorer electrical characteristics, such as lower overload capacity, power factor and efficiency. This applies particularly to tandem motors.

About 25 % of the rolling mill motors manufactured by Asea have been constructed in accordance with the above methods, a circumstance which shows the popularity they have obtained in spite of their drawbacks. In a number of the leading iron works in Sweden, among which can be mentioned Sandviken Iron Works, Fagersta Bruk, Forsbacka Iron Works, Soderfors Bruk, etc., such motors were installed by Asea 20—25 years ago, and are still running perfectly satisfactorily today. With regard to the recovery of flywheel energy (by fixed or automatic slip resistance) everything that has been said earlier regarding single speed motors holds good. It should, however, be noted that with tandem motors the slip must be limited in certain cases to a relatively low value.

At the present time tandem motors are becoming obsolete for rolling mill drives, and are being largely displaced by more modern systems for obtaining several speeds. This applies also to two-speed motors with pole-changing device. This is not entirely to be ascribed to the motor's inferior electrical characteristics, *i.e.* power factor, efficiency, etc., but also in a larger measure to the circumstance that the ability to deal with different rolling programs is more limited with these machines in comparison with more modern systems of speed regulation. When a rolling mill equipment is under consideration, it is generally known what kind of

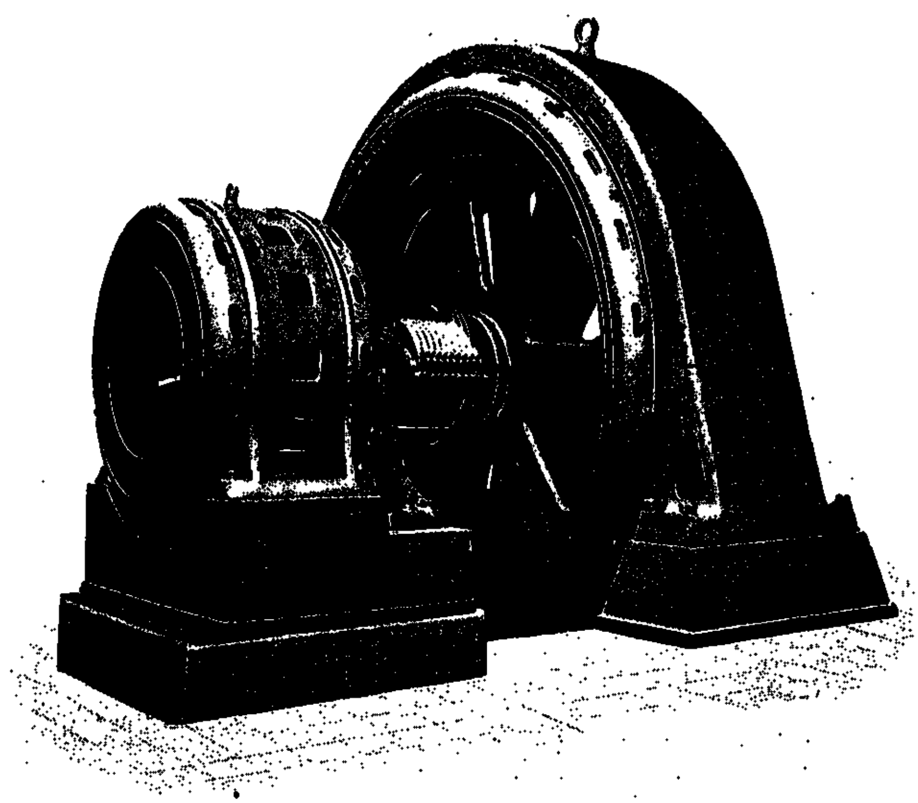


Fig. 11. Asea three-phase tandem motor, 600/535/300 h.p., 182/164/91 r.p.m. for 350 mm rod mill at Sandviken Iron Works.

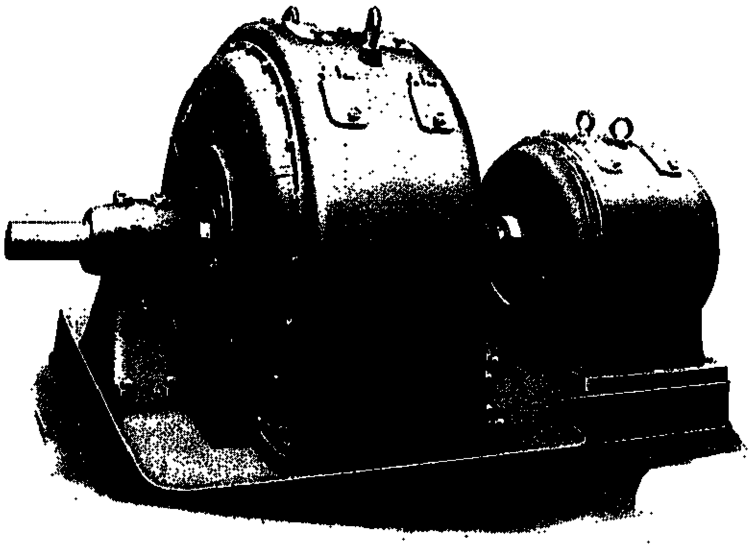


Fig. 12. Asea three-phase tandem motor, 900/780/680/520 h.p., 585/420/365/285 r.p.m. for a 250 mm wire mill at Sandviken Iron Works.

material it is intended to roll at the time, but it is usually impossible to foretell what work may be required in the future. The limitation of a comparatively small number of speeds has accordingly a considerable effect on the possible resources of the plant.

Two-speed motors with two separate windings can still be regarded as up-do-date machines for rolling mill drives, but on the assumption that the work is of such a nature that the two speeds provided will fully satisfy the demands made by the product.

These motors also possess electrical characteristics which are more nearly comparable with those exhibited by single speed motors. As lately as in 1919—1920 Asea has installed such two-speed motors for four rolling mills at Hellefors Bruks A.-B. and Motala Verkstads A.-B. (now A.-B. Lindholmen—Motala). The first of these (Hellefors) consists of a wire rod mill with 8 sets of rolls direct coupled to an 800 h.p. Asea three-phase, two-speed, induction motor, wound for 800 volts, 50 cycles, and designed for synchronous speeds of 500 and 375 r.p.m.; and an intermediate train, rope-driven by a 400 h.p. motor of similar type, 380 volts, 50 cycles, 375 and 250 r.p.m. synchronous.

The installation at Motala consists of a plate and roughing mill, arranged for driving through a reduction gear by an Asea two-speed, three-phase induction motor, 500 volts, 50 cycles, 450 and 300 h.p. at speeds of 500 and $333^1/_3$ r.p.m. (synchronous) respectively. This installation is of special interest as the motor is equipped with automatically regulated slip resistance of the same type as has been described for Avesta Iron Works.

In this installation is included in addition rolling equipment for medium and light work, also arranged for gear drive by an Asea two-speed three-phase induction motor, 500 volts, 50 cycles, 275 h.p. at both 750 and 500 r.p.m. (synchronous).

These motors are with the exception of the one driving the sheet and plate mill equipped with fixed slip resistance, which is so arranged that it can be connected up to give certain different slip values, making it possible to adjust the amount of slip and obtain the most suitable value for each rolling program.

B. *Motors with speed regulation.*

These can also be suitably divided into two groups, viz:

1. Motors running continuously in the same direction.
2. Reversible motors.

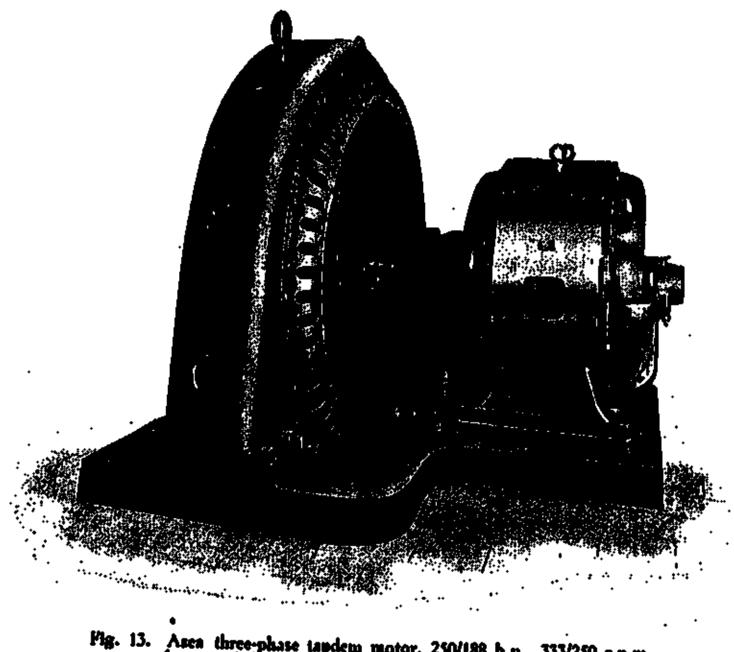


Fig. 13. Asea three-phase tandem motor, 250/188 h.p., 333/250 r.p.m. for a medium rolling mill at Forsbacka Iron Works.

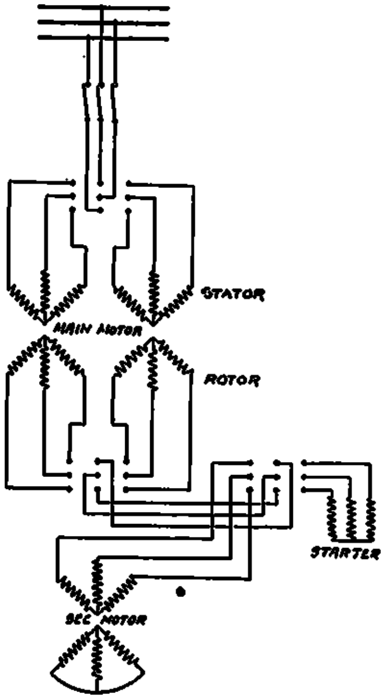


Fig. 14. 4-speed tandem motor.

1. *Motors Running Continuously in the Same Direction.*

For these motors a further distinction can be made between: a) Continuous current systems and b) Alternating current systems.

a) DC Systems.

The rolling mill driving motor is in this case a DC motor either run direct from a DC supply or from a converter supplied with AC. We have already mentioned that the DC motor has been largely employed for rolling mill drives on account of the good speed regulation obtainable.

The speed of a DC motor is regulated by introducing resistance, either into the armature circuit (series regulation) or into the shunt field (shunt regulation), and lastly also by the well-known Ward-Leonard system. Of the above, series regulation has not been very largely used for speed regulation on account of the instability of the speed with varying load. Shunt regulation, which gives a practically constant speed for each value of the shunt field current, can be looked upon as being ideal for a rolling mill drive.

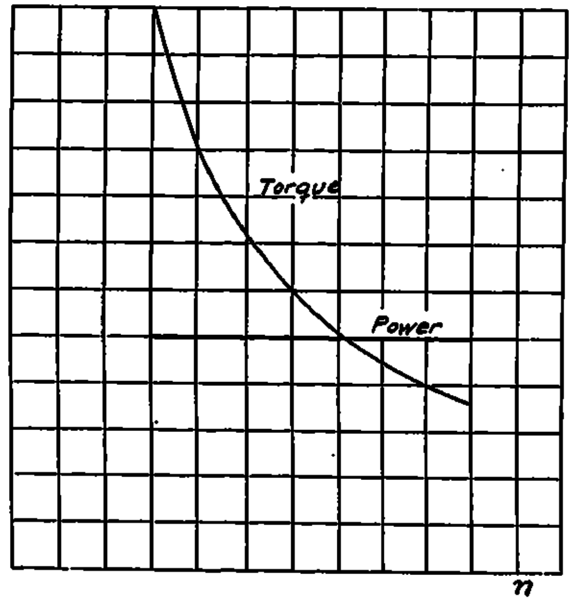


Fig. 16. Torque and power in relation to speed for a shunt regulated DC motor, $mkg = \frac{716 \cdot h.p.}{r.p.m.}$

A DC shunt motor having shunt regulation is capable of practically constant output over the whole speed range, *i.e.* it has an increasing torque with decreasing speed (see fig. 16), which is just what is required in the majority of rolling mills. It is the usual practice to roll the hardest grades of steel at the lowest rolling speeds when the greatest torques are required. In addition the regulation is easily carried out and is practically free from losses.

The third method of regulation, the Ward-Leonard system, has likewise come into use for rolling mills running continuously in the same direction, but this method has become of greater importance for reversible mills. Ward-Leonard regulation is obtained by using an additional motor generator set, the DC generator of which provides the power for driving the rolling mill motor. The voltage of the generator is controlled by regulating its separately excited shunt field by which means the speed of the rolling mill motor which is also separately excited is proportional to the generator voltage

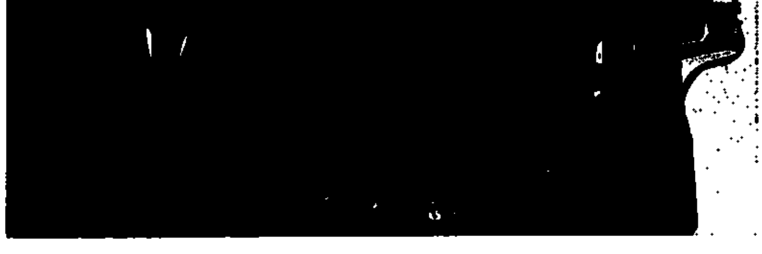


Fig. 15. Asea three-phase tandem motor, 425/340/300 h.p. continuously, 365/290/240 r.p.m. for ingot rolling mill at Bangbro Iron Works.

at each instant. The rolling mill motor consequently gives constant torque between standstill and the required maximum speed, *i.e.* an output increasing directly with the speed (see fig. 18). It is often desirable to use a combination of Ward-Leonard regulation and shunt regulation for rolling mill motors. Suppose a rolling mill is to be regulated between speeds n_1 and n_3, but the maximum continuous output of N h.p. is required at a speed of n_2, above which speed the output can remain constant, *i.e.* by consideration of the required torque the motor is dimensioned for N h.p. at a speed of n_2, with full field, and for shunt regulation between n_2 and n_3 (see fig. 19). In such a case, if pure Ward-Leonard control were employed,

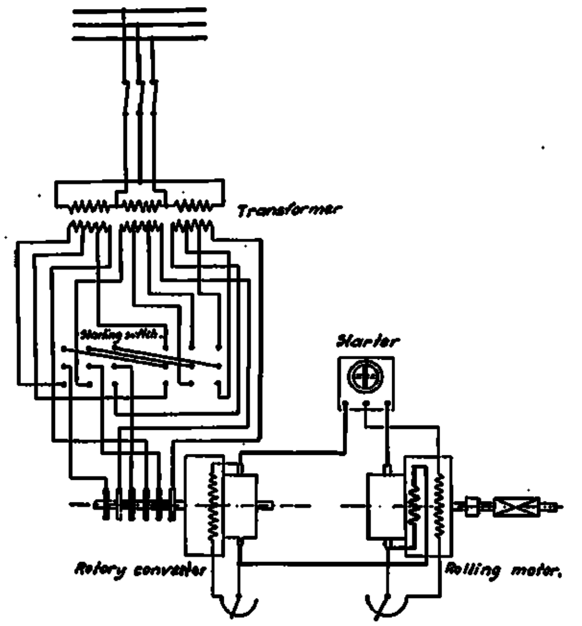


Fig. 17. DC motor connected to rotary converter and transformer.

the size of the motor would certainly be the same, but the generator of the Ward-Leonard set would be larger and both motor and Ward-Leonard set would be less efficiently utilised, as can be easily appreciated by reference to fig. 18. Let for example N h.p. correspond to A amps at a voltage V_2 corresponding to a speed n_2, then a Ward-Leonard generator is required for $V_2 \cdot A$ kW (neglecting losses) which output is kept constant as the speed is increased by weakening the motor field. Accordingly if Ward-Leonard speed control is used alone, the Ward-Leonard generator must be dimensioned for A amps and $\frac{n_3}{n_2} \cdot V_2$ volts, *i.e.* $A \cdot \frac{n_3}{n_2} \cdot V_2$ kW, although the whole of this power is not used in useful work.

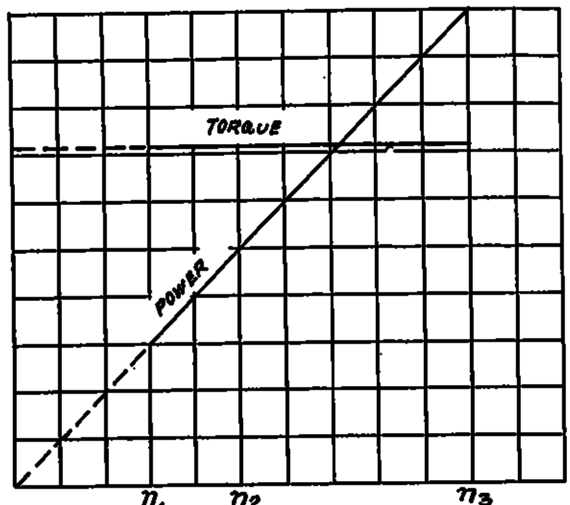


Fig. 18. Torque and power in relation to speed for a Ward-Leonard controlled DC motor. $mkg = \frac{716 \cdot h.p.}{r.p.m.}$

As stated above the Ward-Leonard system of regulation is of by far the greatest importance for reversing rolling mills. For mills running continuously in one direction the Ward-Leonard system should only be used in exceptional cases, e. g. for speed regulation over particularly wide ranges and where it is necessary to reduce peak loads on the supply. In the last case the so-called Ilgner system can be used, *i.e.* a Ward-Leonard set with the addition of a flywheel. The Ward-Leonard unit is then dimensioned for the mean value of the rolling load, while the flywheel is dimensioned so as to be able to deal with the load peaks by slowing the set down. By using automatically regulated slip resistance for the motor of the Ward-Leonard

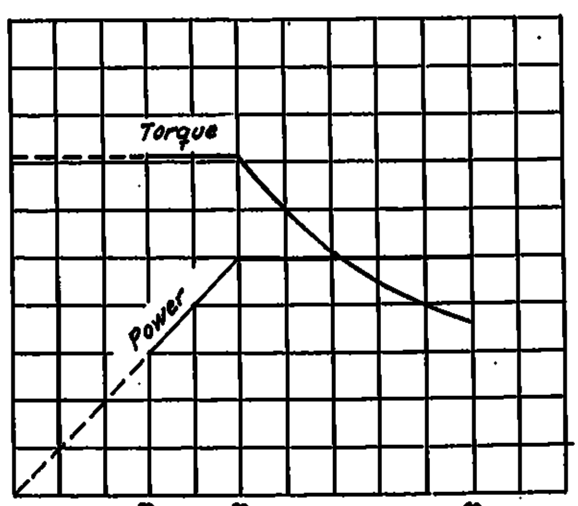


Fig. 19. Torque and power in relation to speed with Ward-Leonard and shunt regulated DC motor. $mkg = \frac{716 \cdot h.p.}{r.p.m.}$

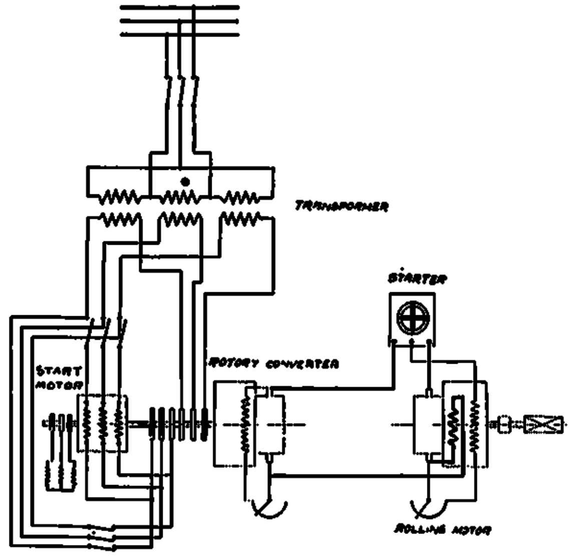


Fig. 20. DC motor connected to rotary converter and transformer. Rotary converter with separate starting motor.

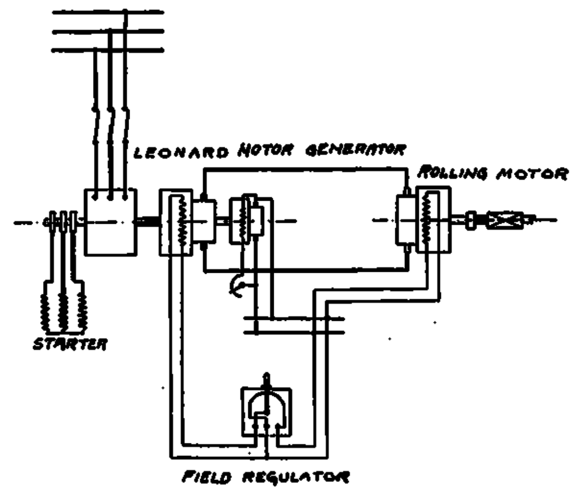


Fig. 21. DC motor connected to motor generator set according to the Ward-Leonard system.

set (if an induction motor) the load on the supply can be kept constant, at any rate within limits, at a value corresponding to the mean value of the power required for rolling.

Fig. 21 shows the principle of connection for a Ward-Leonard system. For rolling mills running continuously in one direction the DC motor with shunt regulation is the most common, and is the system which has been very widely used on the Continent. This system can often be justified even where there is no DC supply.

Conversion from AC to DC can be suitably arranged by a rotary converter, which at the same time can be used as a phase advancer. Where there is a high tension AC supply, the rotary converter is connected to it through a transformer. Figs. 17 and 20 show diagrams of connections for such an arrangement.

At the same time the conversion from AC to DC by means of motor-generators must not be left out of account. As by their use transformers are in most cases unnecessary, and as in many cases motor generators can be run at higher speeds than rotary converters, this method of conversion is often advantageous from the point of view of first cost.

Certainly phase advancing cannot be done without introducing further complications. If phase compensation is required, a synchronous motor can be used instead of a common induction motor.

To recover power from the flywheel, DC rolling mill motors are wound compound, giving a falling speed with increasing load, which is exactly analogous to an induction motor with slip resistance, but differs in the fact that the speed drop of a compound wound DC motor is accomplished, practically speaking, without loss.

Smoothing out the load on the supply can be further accomplished with the Ward-Leonard-Ilgner system by using an additional machine coupled to the converter set and a so-called buffer battery, which acts analogously to the Ilgner flywheel.

b) AC Systems.

Of the methods of regulating the speed of AC motors one of the greatest importance is that which is based on the utilisation of the secondary or rotor power (slip energy).

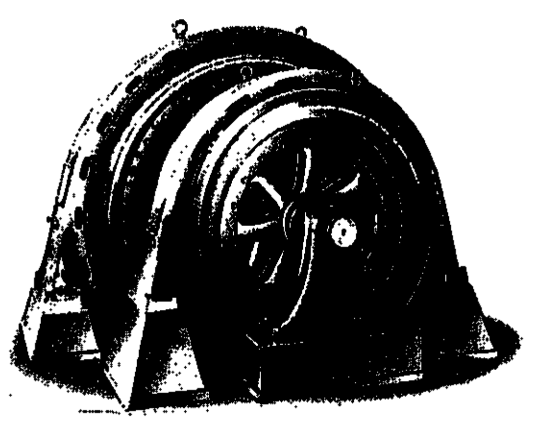


Fig. 22. Asea tandem motor, 850 h.p. continuous, 285/235/200 r.p.m., 280 volts, $66^2/_3$ cycles, for rolling mill at the Hamilton Iron & Steel Company, Canada.

Speed regulation obtained by the use of a secondary regulating resistance which absorbs the slip energy possesses the same disadvantage as the series regulation of a DC motor, *i.e.* the speed varies in proportion to the load.

The above mentioned method, known as the

Kramer system after its inventor, in which the slip energy is utilised, is characterised by the use of a common asynchronous motor as a driving motor the speed of which is regulated by the help of a cascade coupled regulating unit which takes up the power available in the rotor, corresponding to the magnitude of the slip, and makes use of it in some way or other.

On account of the negligible losses in the regulating unit this system of regulation gives a very high efficiency and this fact, more than any other, accounts for the popularity which has been attained by the method.

To obtain actual speed regulation the speed variation possibilities of the DC motor and the commutator motor, which is allied to it in this respect, are made use of. With the help of some of these motors the speed of the main

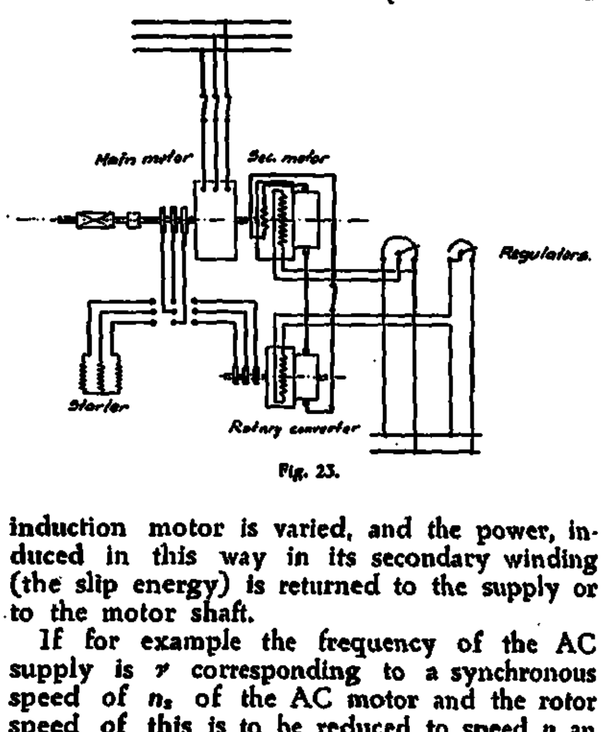


Fig. 23.

induction motor is varied, and the power, induced in this way in its secondary winding (the slip energy) is returned to the supply or to the motor shaft.

If for example the frequency of the AC supply is ν corresponding to a synchronous speed of n_s of the AC motor and the rotor speed of this is to be reduced to speed n an AC current is induced in the rotor the frequency of which is $(1 - \frac{n}{n_s}) \cdot \nu$, or $s \cdot \nu$, where s is the percentage of slip and if the power given out by the motor is N synchronous h.p. the slip power is $s \cdot N$ h.p. If this last quantity, as in the case of the employment of slip regulating resistance, is not made use of then at a speed n and with a normal output N there would only remain $N(1-s)$ h.p. for useful work.

In its oldest and most commonly used form the arrangement in question consists of an induction motor connected to the AC supply (the main motor), a DC motor mechanically and

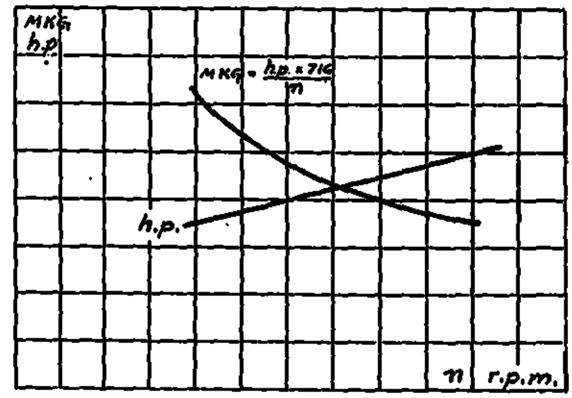


Fig. 24.

electrically coupled to it (the secondary motor), and a rotary converter. The electrical connection between the main motor and the secondary motor is carried out through the rotary converter whose primary (AC side) is connected to the secondary motor's armature, see fig. 23.

Speed regulation is obtained by regulating the shunt of the separately excited secondary motor. With full excitation of the secondary motor, *i. e.* when the whole of the shunt resistance is cut out, the unit runs at its lowest speed; the main motor with maximum slip, and the rotary converter with maximum frequency.

When the whole of the shunt resistance is in circuit, *i. e.* with a weak field on the secondary motor, the unit runs at its highest speed which is about 10 % under synchronism, so that the slip of the main motor is low and the frequency of the rotary converter so decreased that it is only just turning over.

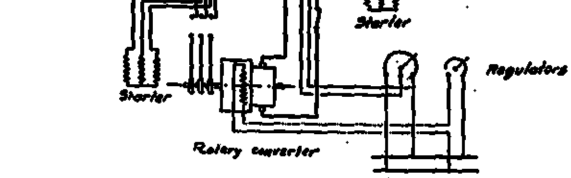


Fig. 25.

The upper limit to the speed accordingly depends on the lowest frequency at which synchronising power can be obtained for starting the rotary converter. In general the limit is found

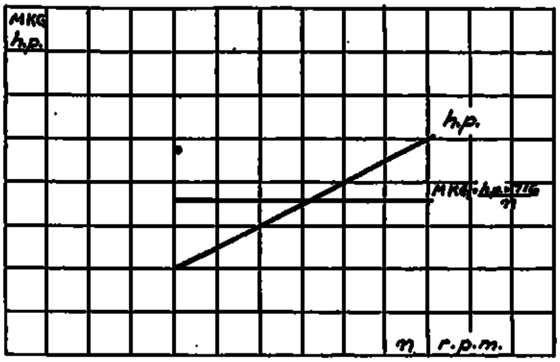


Fig. 26.

to be 10 % below the main motor synchronous speed. Between the speed corresponding to synchronism and a speed about 10 % below this, accordingly, no regulation is possible.

The region within which regulation is possible is theoretically unlimited but on account of practical considerations a greater variation than in the ratio of 1:2 is in general not advisable. With a greater amount of regulation than this the size of the secondary motor must be increased very considerably and the whole system becomes more expensive and uneconomical.

The rotary converter which is also separately excited acts as an intermediary between the rotor of the main motor and the secondary motor so that the main motor is able to give practically constant power over the whole range of speed variation.

It should be noted that the main motor must be so designed that it can carry the full load current even at the lowest speed without undue temperature rise.

The rotary converter must be designed for an output of $s \cdot N$ h.p. with a frequency of $s \cdot \nu$ and the secondary motor for an input of $s \cdot N \cdot \eta_0$ at a speed n where η_0 is the efficiency of the rotary converter.

The slip power returned to the shaft of the main unit is accordingly $s \cdot N$ decreased by the losses in the rotary converter and secondary motor, *i.e.* $s \cdot N \cdot \eta_0 \cdot \eta_b$ where η_b is the efficiency of the secondary motor. Thus a theoretically constant output cannot be obtained at the shaft of the main unit although with the usual amount of speed variation the falling off in this power is not considerable (a maximum of from 5 to 10 %).

Another useful characteristic of this system is that the motor can work at high power factor due to the presence of the rotary converter which can be made, without trouble, to act as phase advancer. The efficiency obtained is also as good as that for a single speed asynchronous motor, in reality somewhat better than for such a machine, since there are no losses in external rotor resistance. The reduction of speed necessary to make use of the flywheel effect of the set is obtained by compounding the secondary motor. Here again the drop in speed should be kept within suitable limits especially at the lowest running speed when the secondary motor works with "saturated" field. Otherwise a larger secondary motor must be installed.

An advantage from the point of view of standby plant is that if any breakdown should take place during running on the various secondary machines work need not be held up as it is possible to continue to run with the main motor alone as an ordinary induction motor.

Fig. 24 shows the variation of power and torque as a function of the speed showing a somewhat increasing torque as the speed falls. This covers the requirements usually met with for rolling mill drives. At the same time, as pointed out above, the unit can very well be designed for practically constant output and with torque increasing in proportion to the falling speed, but naturally at the cost of using somewhat larger machines.

If the unit is built for a relatively small output the rotary converter and secondary motor can be suitably replaced by a commutator motor.

In the above we have only dealt with cases

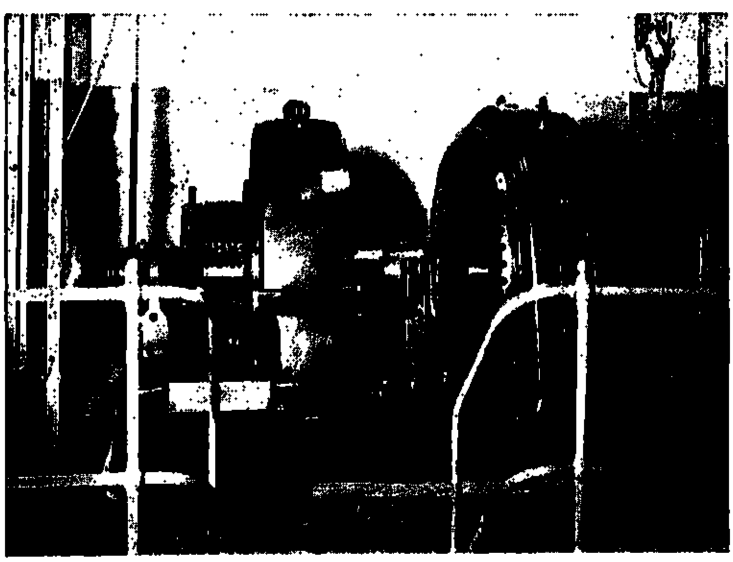


Fig. 27. Variable speed rolling mill motor, Asea-Kraemer system, 1,000—660 h.p., 350—230 r.p.m., at Klosters A.-B., Stjernsund.

where the slip power is returned to the shaft of the main motor unit. Although this is in general most suitable it is possible in certain cases to make use of the same principle by returning the slip power to the supply. An occasion for this would be where it is only necessary to get the same torque over the whole range of speed, *i.e.* where the output is required to be proportional to the speed (see fig. 26). For returning the slip power to the supply there are several methods. Thus it can as before be converted to DC in a rotary converter which however is connected to a separate motor generator consisting of a DC motor and an asynchronous AC generator in accordance with fig. 25. Here also the rotary converter and secondary motor can in certain cases be replaced by a commutator motor. Further the slip power can be returned to the supply through a frequency converter connected to the supply through a booster transformer.

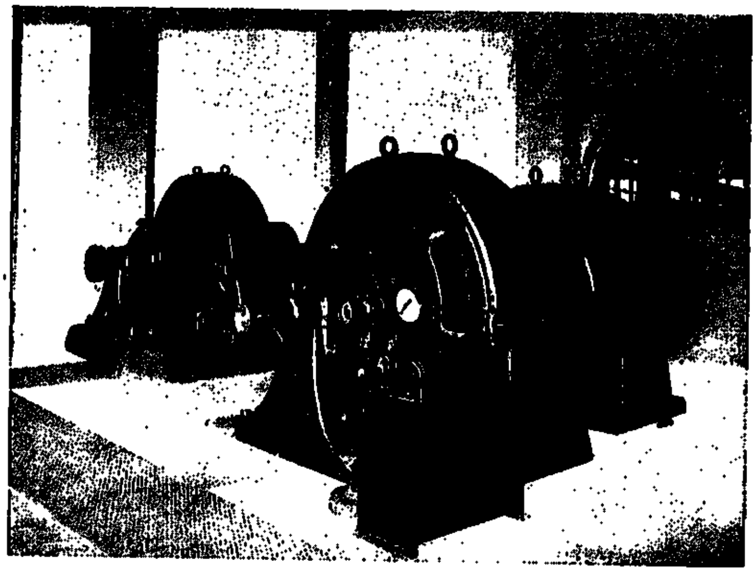


Fig. 29. Variable speed rolling mill motor, Asea-Kramer system, 700 h.p., 600—300 r.p.m., at Horndals Iron Works.

Of the advantages obtained by returing the slip power to the supply, the fact that only one motor in the main driving unit is necessary may be mentioned, as this saves considerable space. Further there is nothing to prevent the regulating machines being driven "backwards", *i.e.* used to take energy from the supply and thereby run the main motor which can thus be driven above synchronous speed.

The rolling mill motors which have been constructed by Asea on the principle under consideration have all been designed for returning the

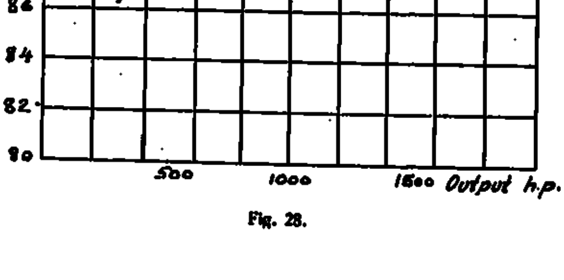


Fig. 28.

slip energy to the shaft of the rolling mill motor by means of a secondary motor direct coupled to it.

The first units which were delivered were set to work in 1916 and 1917, namely one of 1,000—660 h.p. at 350—230 r.p.m. (428 r.p.m. synchronous), 500 volts three-phase 50 cycles, for a wire mill belonging to Klosters A.-B., Stjernsund, and one of 700 h.p. at 600—300 r.p.m. (750 r.p.m. synchronous), 600 volts, 50 cycles, also for a wire mill, belonging to The Horndals Iron Works A.-B.

The first-named unit displaced a steam engine which was direct coupled to the roughing mill and ran the finishing train through a rope drive. The electric set is direct coupled to the finishing mill and by means of the original rope transmission drives the roughing mill, which is provided with a 19-ton flywheel. The steam engine has been retained as a stand-by.

Fig. 28 shows the values of the efficiencies obtained as determined on site. The production of the mill reaches 1½ tons of finished wire per hour.

The installation at Horndal consists of a wire rod mill with 8 sets of rolls, and a billet train driven from this by means of a belt. This installation is of special interest on account of the starting arrangements. Since the highest rolling speed is 600 r.p.m. it was hardly possible to allow the mill to run at the synchronous speed of 750 r.p.m., so that it was found necessary to use a method of starting which differs from that generally adopted. The usual method is to run the main motor up to synchronism, after which the fields of the auxiliary motor and rotary converter are adjusted to suitable values corresponding to the speed actually required at the time. With the plant in question it is necessary to

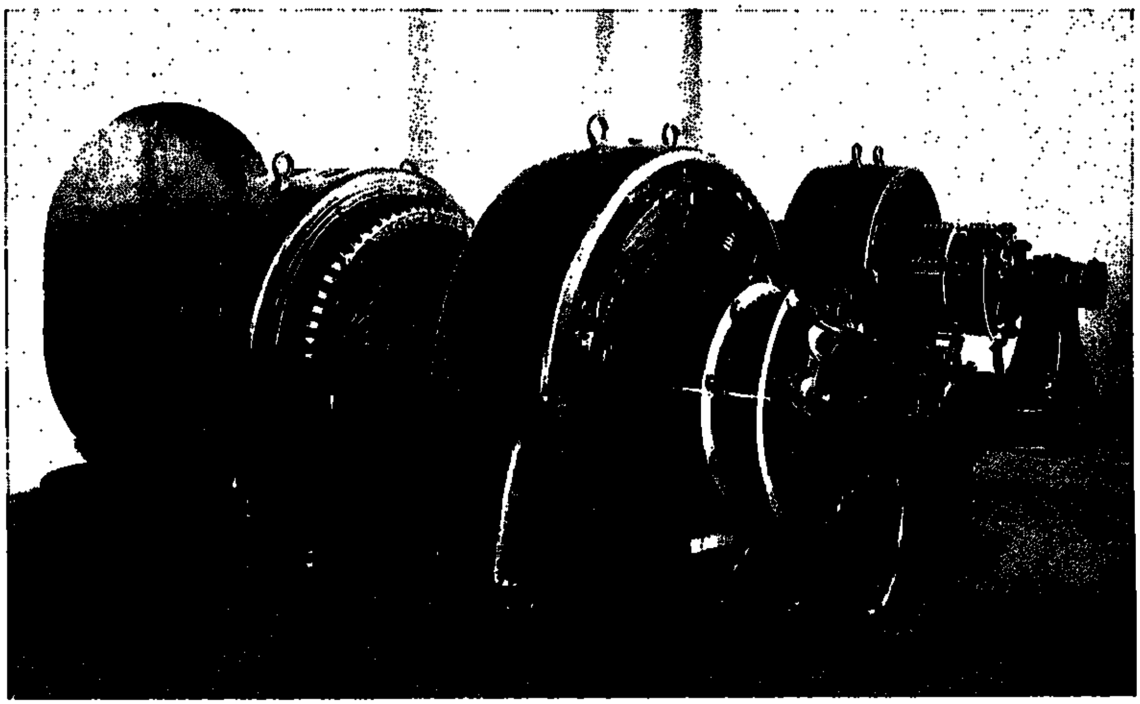


Fig. 30. Variable speed rolling mill motor, Asea-Kramer system, 1,200—900 h.p., 450—250 r.p.m., at Boxholms A.-B.

parallel the main motor and the speed regulating machines before synchronism is reached. As a protection against overspeed a centrifugal switch is carried on the shaft end of the main motor, which at a predetermined maximum speed, trips the main circuit breaker. The method is somewhat troublesome and would not be adopted unless, as in the present case, it was found to be

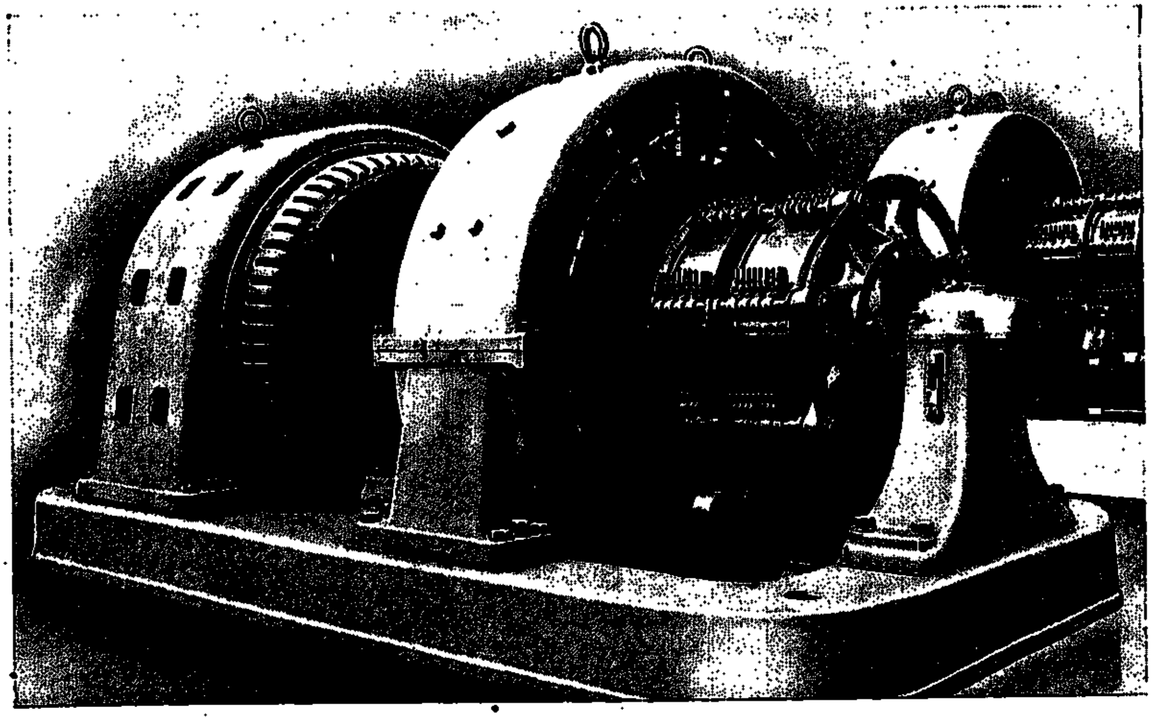


Fig. 31. Variable speed rolling mill motor, Asea-Kramer system, 800 h.p., 430—230 r.p.m. at Larsbo-Norns A.-B.

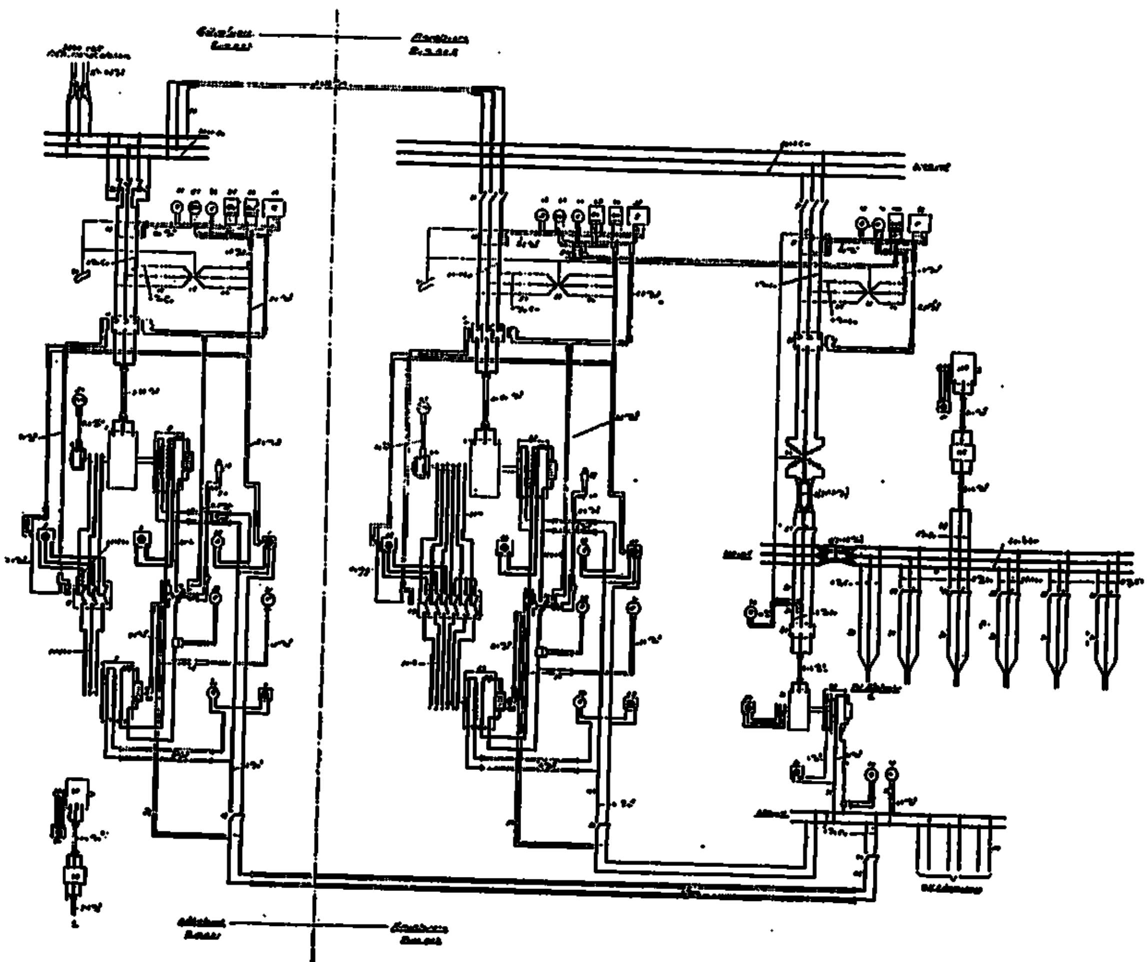


Fig. 32. Diagram of connections for rolling mill installation at Larsbo-Norns A.-B., Wikmanshyttan.

absolutely necessary, especially where a high starting torque is to be expected. The two installations referred to, which were manufactured at about the same time, have been followed by a number of somewhat similar sets. The rapid advance in the employment of machines on this system is a witness to the popularity they have obtained. It is also of interest to mention that the same units can be used equally well for rod mills and finishing mills and for a variety of qualities of steel, (special steels). A unit delivered abroad (to Spain) is the largest supplied by Asea as regards actual machine frame sizes, and is designed for 1,000—750 h.p. continuously at 120—85 r.p.m. (150 r.p.m. synchronous) at 5,000 volts three-phase, 50 cycles.

Among the latest machines delivered can be mentioned one unit for a continuous output of 1,200—900 h.p., 450—250 r.p.m., 750 volts three-phase, 50 cycles, for a wire mill at Boxholms A.-B. The billet train in this case is driven by a separate three-phase induction motor of 275 h.p. through a rope drive. The variable speed unit is direct coupled to the wire rod mill, and at the same time runs the intermediate train through a rope drive.

Further to the above, two units have been supplied to Larsbo-Norns A.-B., Vikmanshyttan, of which one is for 400 h.p. at 430—200 r.p.m., 3,000 volts three-phase, 50 cycles, for a combined billet and rod mill, and the other of 800 h.p. at 430—230 r.p.m., 3,000 volts three-phase, 50 cycles, for a finishing mill.

The former unit drives on to a large rope wheel placed with the flywheel on the shaft of the rolling mill, while the finishing mill motor is direct coupled to the finishing rolls and drives the billet train through ropes. Both the auxiliary motors of these units are compounded for a speed drop of 25 % and 15 % respectively as a maximum with normal full load.

Fig. 32 shows the connection diagram for the complete installation. The various details employed in the apparatus and instrument equipment

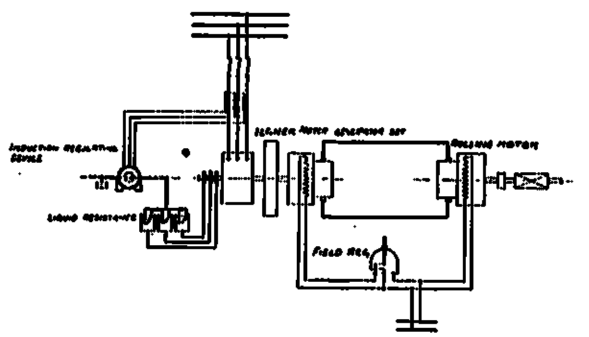


Fig. 33. Simplified diagram of Leonard-Ilgner system.

are in general Asea's usual standard for such installations, but the protective devices which practically obviate incorrect operation may be referred to.

a. The main oil switch is provided with an interlocking relay which makes it impossible to close the main switch unless:

1) the starter of the main motor is in the starting position, 2) the change-over switch between the main motor and the rotary converter is in its position connecting the main motor with its starter, and 3) the shunt regulator for the auxiliary motor is in the starting position.

b. The main oil switch is released as soon as the automatic overload circuit breaker between the rotary converter and the auxiliary motor is opened for any reason. The main switch cannot accordingly be closed unless this circuit breaker is closed.

c. The overload circuit breaker, which is furnished with no-volt release, opens either if the current is too great, or if the field circuit voltage sinks to an insufficient value.

d. On the shaft end of the rotary converter is placed a centrifugal switch which opens the circuit breaker in the event of the speed increasing above a determined maximum.

The machines are generally of standard open type, for erection in a special machine room which is usually ventilated from a separate fan unit maintaining excess pressure within the room, so as to prevent the entrance of dust from the rolling mill, while at the same time the machines themselves receive plenty of cooling air. The starters are constructed with strong cast iron grids mounted in frames covered with sheet iron, and are provided with contacts immersed in oil. The switchgear and instruments are supported on strong angle iron frames which are covered at the front and sides with black enamelled sheet steel.

The instruments used on the primary AC side are ammeter, voltmeter, kWh meter, indicating wattmeter, and power factor meter, and on the secondary side, ammeter and voltmeter between the rotary converter and auxiliary motor, and ammeters for the shunt field circuits.

In addition there is a recording tachometer operated from a tachometer dynamo driven from the shaft of the rolling mill motor, by which the speed can be accurately read at any instant; accordingly all necessary instruments are included for complete control of the machines.

2. *Reversing Motors.*

Here the Leonard-Ilgner system practically has the monopoly for rolling mill work.

Reversing rolling mills are in most cases built for heavy work on the two-high system, *i.e.* with two parallel rolls for rolling ingots, girder sections, rails etc. of the largest dimensions. The material is rolled alternately in both directions, which makes it necessary to reverse the direction of running of the rolling mill motor between each pass. The work of the motor accordingly does not only consist of actual rolling (changing the shape of the material), but also of very frequent starting and reversing. The running is thus very intermittent and subjects the machinery to a great amount of wear and tear, from which it follows that a rolling mill of this kind built for heavy work requires an exceedingly large power for driving it. No suitable electric drive for reversing rolling mills has

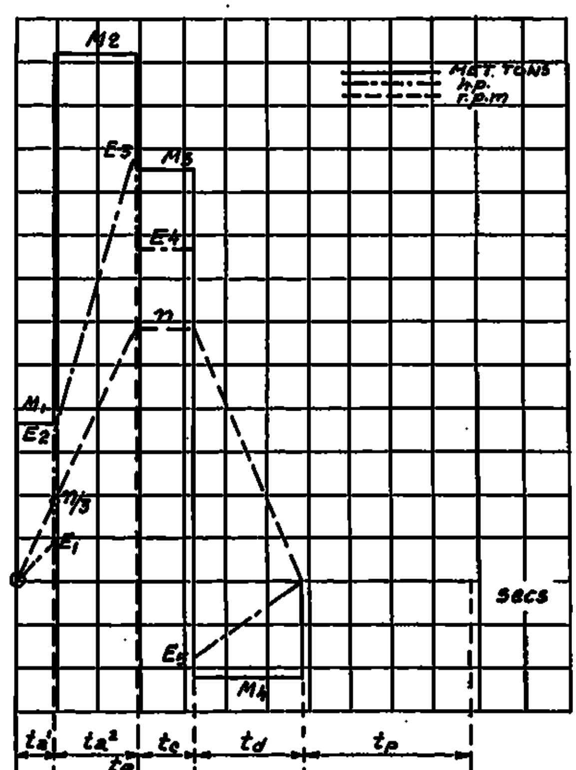


Fig. 34.

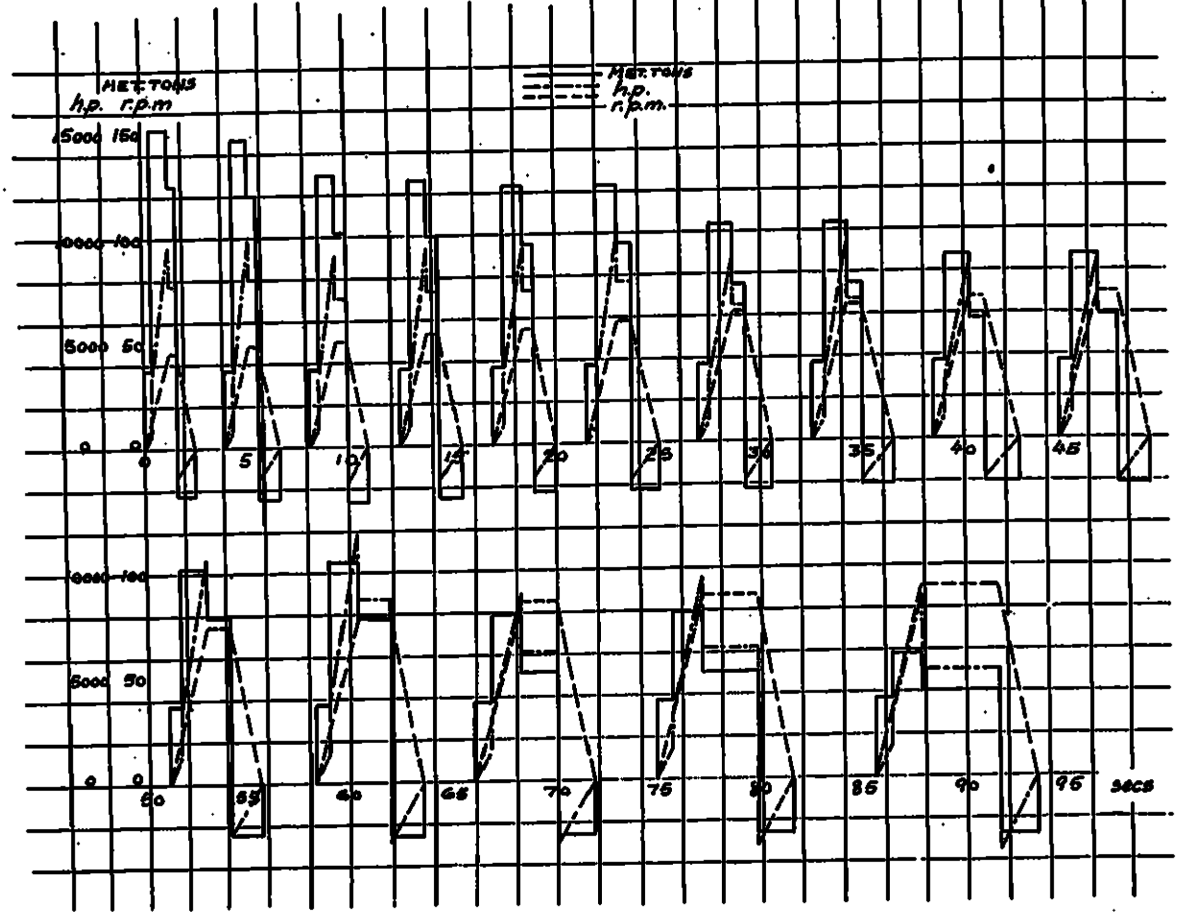


Fig. 35.

been found so far other than the Leonard-Ilgner system. On account of the particularly simple and easily operated regulating and reversing permitted by a motor working on the Ward-Leonard principle, and on account of the smoothing out of the load which the Ilgner principle makes possible, the Leonard-Ilgner system can be regarded as an ideal solution of the problem and one of the finest achievements in the domain of electrotechnics.

For a closer understanding of the different phases in the work a motor running on this system has to carry out on a reversing rolling mill, we refer the reader to fig. 34 which shows the speed of rolling, torque, and power during one pass.

Looking first at the speed time diagram, the rolls reach full speed according to the figure after a time $t_a^1 + t_a^2$, which is accordingly the total time of acceleration. The time t_a^1 is the time taken to accelerate the rolls up to the gripping speed, *i.e.* the speed at which the billet engages with the rolls. As a suitable mean value of this it is usual to reckon with about one-third of the maximum speed. The time t_a^2 is the remaining time of acceleration for reaching the maximum speed n, and t_c is the time of running at full speed. During a time $t_a^2 + t_c$ the billet being worked is actually in the rolls, and this time may be called the "effective" time t_e. The time t_d is the time of retardation or the time taken to bring the machinery to a standstill, while t_p is the pause which follows before the start of the next pass. On the torque diagram, M_1 is the sum of the friction torque and the necessary torque for accelerating up to the speed $n/3$, and the corresponding power on the power diagram is E_1. M_2 is the sum of the friction torque and the necessary torque for acceleration up to speed n and for rolling during the time t_a^2. The corresponding values of power are E_2 and E_3. The torque M_3 is the sum of the friction torque and the necessary torque for rolling at speed n corresponding to the power E_4. Lastly M_4 is the retarding torque decreased by the friction torque and the corresponding power E_5, under the assumption that the billet leaves the rolls at their full speed n.

The work done by the electric motor during such a rolling period is accordingly the following-

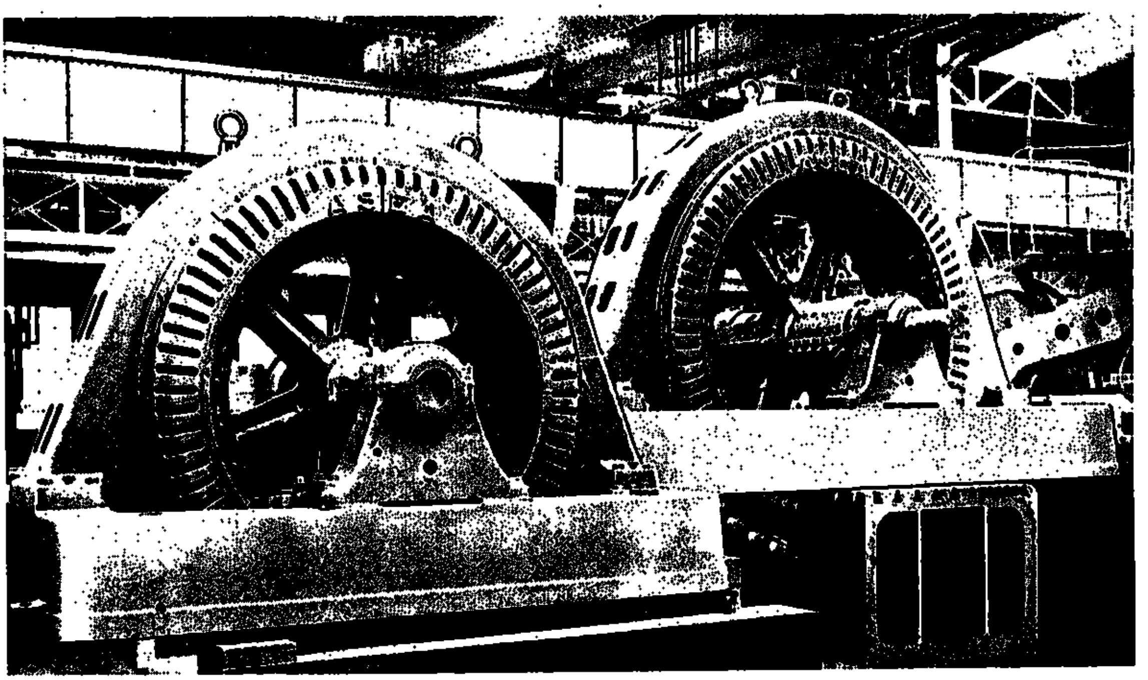


Fig. 36. Two rolling mill motors for Sandvikens Iron Works, Sweden. To left: Three-phase motor, Type M 165, 600 h.p. at 250 r.p.m. To right: Two-speed three-phase motor, Type M 185, 800/535 h.p. at 250/167 r.p.m.

ing: during time t_a^1 the rolling mill motor and the rolling mill accelerate with no load from standstill to the speed $n/3$. During the time t_a^2 the motor and rolling mill accelerate while rolling is being performed from the speed $n/3$ to n, after which the motor during time t_c supplies the necessary torque for rolling at speed n plus the friction torque. In all the above phases the Ilgner generator supplies the necessary power with the help of the flywheel which is accordingly slowed down.

During time t_d the motor and rolling mill are retarded at no load from speed n to standstill. If the retardation is carried out sufficiently quickly *i.e.* if the time t_d is sufficiently short, there is a recovery, corresponding to the amount by which the retarding torque exceeds the friction torque, by the Ilgner generator, which then runs as a motor driven by the rolling mill motor and speeds up the flywheel. The continually repeated reversing of the rolling mill motor does not occasion losses of any great consequence. During a reversing period, *i.e.* a speed variation from $+n$ to $-n$ r.p.m. the torque of the motor is certainly reversed in the same way, but as the speed passes the zero, *i.e.* changes from + to —, the sign of the power also changes since the power is the product of torque and speed. This means among other things that the rolling mill motor runs as a generator between the speeds $+n$ and 0, but as a motor between the speeds 0 and $-n$. With the Ilgner generator the above is reversed. During the first-named period this works as a motor and accelerates the flywheel, and during the latter period as a generator and retards the flywheel. The energy of rotation of the rolling mill motor is accordingly first transferred to the flywheel and afterwards returned again. The power taken from the supply during the reversing period should be zero in accordance with the above if no losses occurred in the machines or conductors connecting them. Practically the amount of power required is just sufficient to meet these losses, and this means quite a small demand. The importance of this will be quite clear when it is considered that the number of reversals in most cases is considerable, often amounting to 15 or 20 per minute.

For increasing the output of the mill it is usual to increase the speed successively as the length of the billet or bar being rolled increases from pass to pass, and this speed increase during the later passes is obtained by means of shunt regulation of the rolling mill motor. Naturally the torque of the motor decreases, due to shunt regulation in proportion to the increase in speed obtained, but in general there is no cause to fear overloading, as the torque necessary for rolling decreases as the billet is rolled out to a longer length at greater speed.

The high frequency of reversing which is common makes it essential to keep the flywheel effect of the rolling mill motor itself down to a minimum. As large powers are in question of

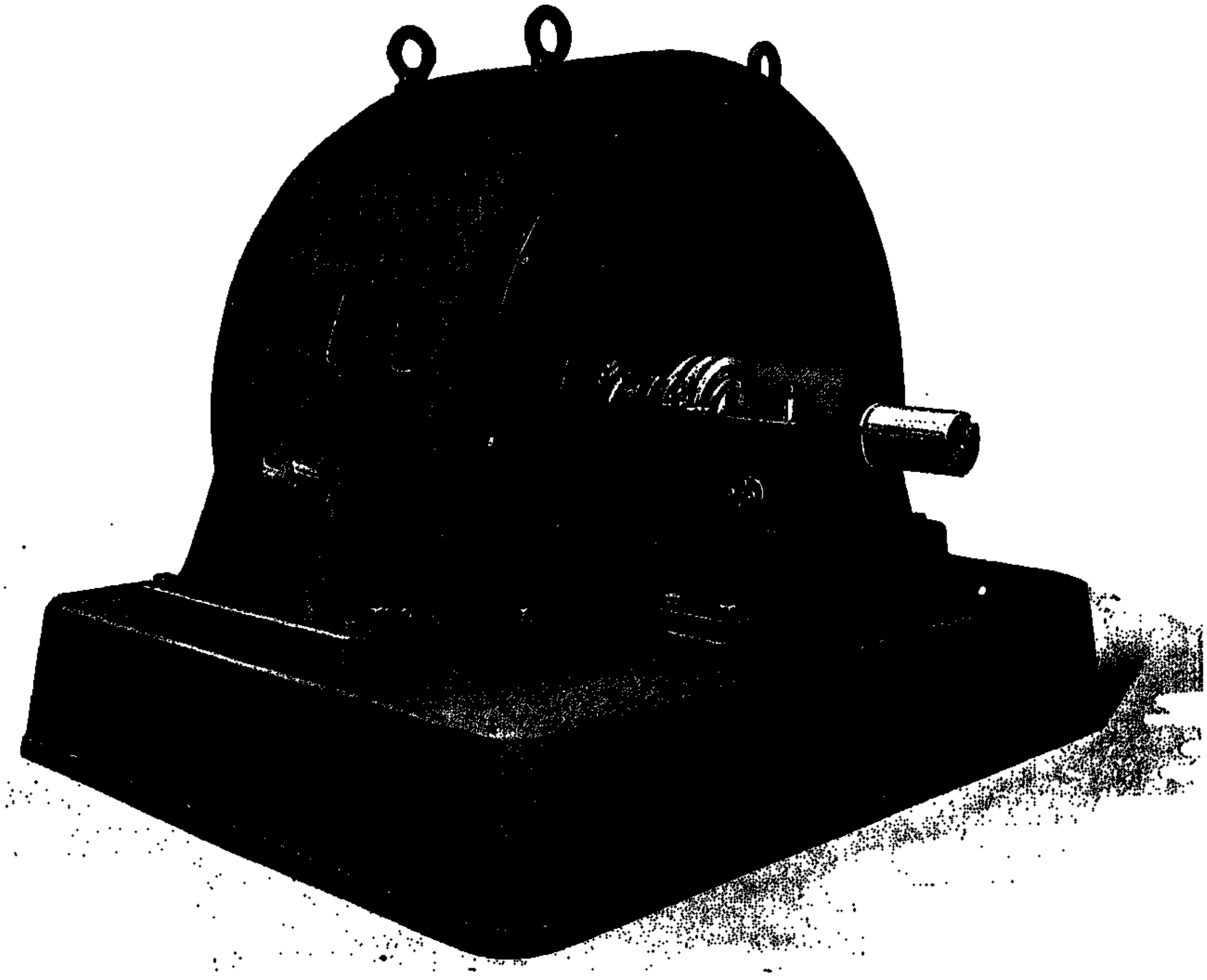


Fig. 37. Three-phase rolling mill motor, Type M 148, 320 h.p., 245 r.p.m.

8,000 to 10,000 h.p. and above, and relatively high rolling speeds (greater than 100 r.p.m.), it is usual to divide the motor into two or more direct coupled units, by which means the total flywheel effect is much smaller than if the whole output was obtained from a single machine. This division into two or more units also introduces an advantage on the electrical side, since it is possible by connecting the units in series to keep the voltage between the generator and motor relatively high, and in this way the current, and accordingly the dimensions of the conductors, are decreased and commutation improved. For this last reason the Ilgner generator also is generally divided into two or more units.

The large amount of power required by heavy reversing rolling mills makes it essential to utilise as fully as possible the energy stored in the flywheel. This is effected by a regulating device of some kind or other which works automatically as the load changes, varying the speed of the Ilgner set and accordingly of the flywheel. If the motor driving the Ilgner generator is an induction motor, the most usual arrangement is a liquid resistance and induction regulating device (see fig. 33), but there is naturally nothing to prevent the utilisation of other means already described, embodying metallic resistances and solenoid operated relays and switches, indeed experience shows that this last method, in conjunction with the Ilgner system can be of advantage in many cases.

If the Ilgner generator is driven from a DC supply, *i.e.* by a DC motor, the energy in the flywheel can be utilised in the same manner by suitable compounding or some other automatic method of strengthening the field. For example, the field of the motor can be divided into con-

stant and variable parts, the latter separately excited from a special generator, the field of which is altered automatically as the load current changes.

In rolling mills of the type under consideration it is possible by effective use of the flywheel to keep the relation between the power taken from the supply and the power required by the rolling mill motor, or the relation between the normal output of the Ilgner generator and the rolling mill motor at a ratio figure not less than 1:6. This relation is, however, entirely dependent on the rolling which is being carried out. The figure mentioned can certainly only be obtained if rolling is done in exceedingly short passes, *i.e.* rolling short lengths. Accordingly, if the material is rolled in greater lengths (longer passes), the relation sinks rapidly and is usually found to be from 1:3 to 1:2.

Fig. 35 shows the calculated torque and power diagram for a 1,000 mm reversing rolling mill for rolling 4-ton ingots from 530 × 530 mm to 150 × 150 mm square in 15 passes and with an estimated capacity of from 90 to 100 tons per hour. On the assumption that about 60 seconds are lost between each rolling period, *i.e.* from the time when the completely rolled ingot leaves the last rolls until the next ingot reaches the cogging rolls, there is a time of approximately $1^1/_2$ minutes for rolling each ingot. During this last named time, accordingly, 15 starts and reverses have to take place. The speed of the motor and the rolls respectively varies between 45 and 90 r.p.m. of which from 60 to 90 r.p.m. is obtained by shunt regulation of the rolling mill motor.

From the calculated diagram the rolling mill motor must be capable of giving a continuous output of 5,000 h.p. at ± 60 r.p.m. and must be able to deal with overloads up to about 13,000 h.p., while the Ilgner generator must be able to give continuously 4,200 kW and be driven by a 2,500 h.p. motor connected to the supply and to a flywheel having a rotational energy of about 6,700,000 kgm, corresponding to approximately 90,000 h.p. × seconds at 375 r.p.m.

The description which follows is from the pen of Professor *A. Lindstrom*, and was published in our Swedish Journal in December 1917. At the present time it is of equal interest, and as regards the details of the electrical installation described, requires no alterations, as the plant has run without any change since it was first set to work. The description may very suitably be included as a conclusion to the general treatment given above. It is inevitable of course that certain repetitions occur, but we do not consider that this is a serious disadvantage.

ELECTRIC ROLLING MILL AT DOMNARVET.

I. DESCRIPTION OF THE PLANT.

The Rolling Mill. The Stora Kopparbergs Bergslag installed a steam driven reversing rolling mill at Domnarvet in 1907, and have since put down a further plant of the same kind. One of the steam engines drives a universal mill and a breaking mill; the other engine drives a rail mill and a girder rolling mill. On account of the great advantages which were shown to be possible by driving such rolling mills electrically and which have been demonstrated by a number of plants put down in various countries, it was decided in 1913, as cheap electric power was available from the hydro-electric station owned by the company, to instal a further rolling mill, to be electrically driven. The whole of the electrical machinery and apparatus required were delivered by Allmänna Svenska Elektriska Aktiebolaget of Vesteras.

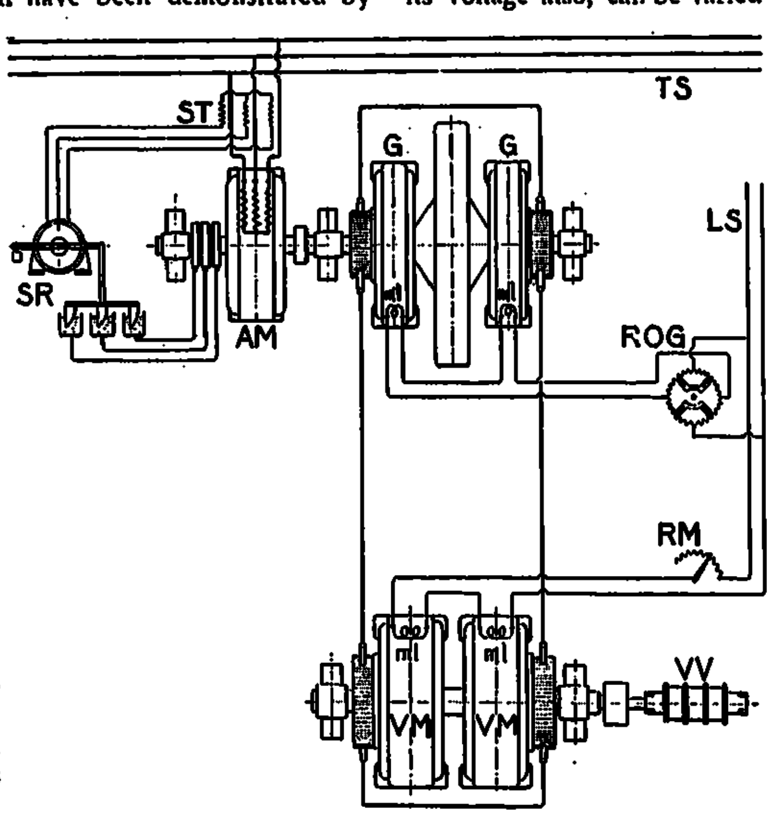


Fig. 1. Simplified connection diagram of Leonard-Ilgner system.

It was further decided to move the universal mill together with its steam engine to a different part of the works, and to arrange for driving the steel mill alone electrically. Later, after removing the shaft of the second steam engine, it has been made possible by using a special shaft extension running in the crank-shaft bearings of the engine to couple up the bar mill to the electric motor and drive it through the steel mill. These mills, which are both 750 mm mills, work in general in succession and very seldom at the same time. Electric rolling has now been in operation for over five years.

The Electrical Equipment. The electric drive is arranged on the Leonard-Ilgner system, which had been proved to be particularly suitable for this class of work, and the main points of which will be first described.

An ordinary (induction) three-phase motor (fig. 1) is direct coupled to a DC generator which delivers current to a DC motor direct coupled to the rolling mill. For certain reasons both the generator and motor are constructed as double machines. The field current for motor and generator is obtained from a separate supply. The field current of the generator and, during the time its speed is practically constant, its voltage also, can be varied within wide limits by a regulator (ROG in fig. 1), namely between a positive and negative maximum value. As long as the field current of the motor is kept constant, its speed and direction of rotation is changed precisely as the voltage and polarity of the generator is altered, *i.e.* practically speaking, as the generator field current is altered. It accordingly follows that the rolling mill can be driven in either direction at any desired speed, simply by regulating the current in the field circuit of the generator. For obtaining higher speeds the motor itself is provided with a rheostat in its field circuit (RM).

The above system of rolling mill drive, the so-called Ward-Leonard system, is not in general suitable by itself; the large variations in the load on the motor due to the rolling and to the reversing (in this case between 0 and 10,000 h.p.) are transmitted through the generator and the three-phase motor, practically undiminished, to the supply and the generating station.

To diminish these peak loads the motor generator set is provided with a heavy flywheel (I) — known as the Ilgner wheel, and the Ward-Leonard system thereby becomes the Leonard-Ilgner system. The function of the fly-

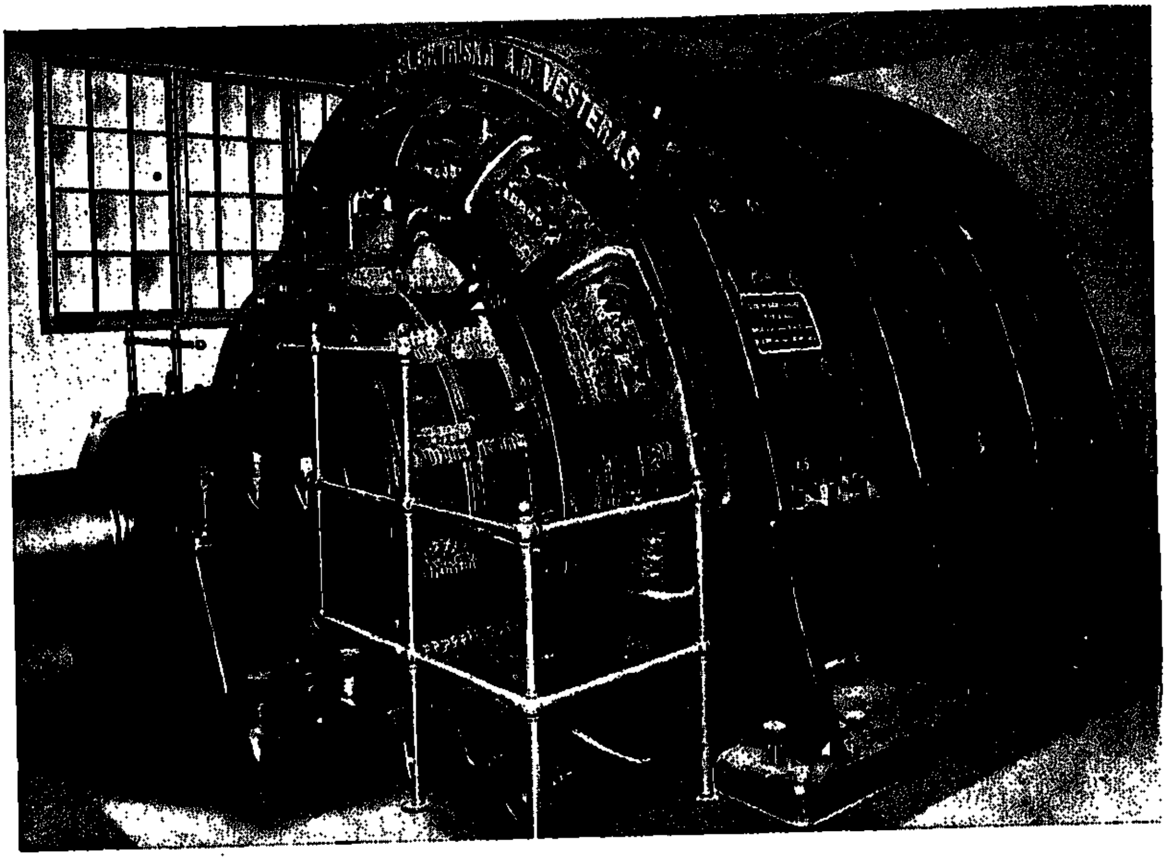


Fig. 2. Rolling mill motor.

wheel is exceedingly important and quite easy to understand; when the rolling mill motor is giving a large output the generator is chiefly driven by the flywheel, and for this reason the three-phase motor is designed to give a suitable speed drop (10—15 %). At the end of the rolling period the three-phase motor again accelerates the flywheel to full speed. The effect of the widely varying power demand of the rolling is accordingly alternatively to increase and decrease the speed of the motor generator set and flywheel, while the three-phase motor takes a practically constant amount of power from the supply, corresponding to the mean power taken by the rolling mill — naturally increased by the losses in the system. By this wonderfully simple principle it is possible to alter the speed and direction of running of the heavy motor quite easily, and the powerful shocks are taken up in the system itself.

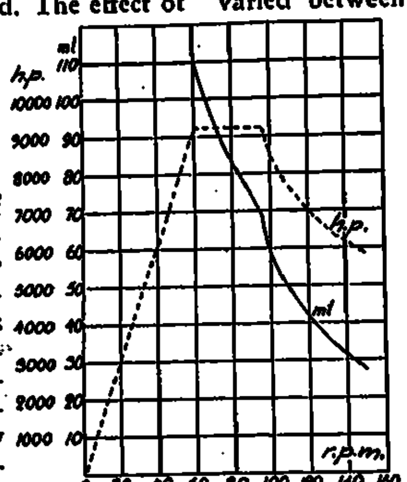


Fig. 3. Maximum torque and output of rolling mill motor.

In its practical details the system is naturally not quite so simple as the above, and this also applies to the description which follows.

The Rolling Mill Motor. The rolling motor (fig. 2) is as we have said, a double machine, and consists of two similar mechanically and electrically connected motors. The speed can be varied between + 60 and — 60 r.p.m. by varying the field current of the generator, and also from between 60 and 150 r.p.m. in either direction, by regulating the field current of the motor itself.

Maximum Output. The horse power which the motor can develop at different speeds is given by the curves in fig. 3. The maximum torque goes up to 110 ton/metres and the maximum output to 9,200 h.p. (6,800 kVA). It is clear that such a motor must have a considerable flywheel effect, and that rapid reversing must necessarily require a considerable torque to effect.

Reversing. The motor must be

reversed sufficiently quickly not to interrupt the rolling, and in this respect a condition for the acceptance of the machine was that it should be possible to reverse at no load and 60 r.p.m. 24 times in one minute. Actually the flywheel effect of the motor $GD^2 = 190{,}000$ kgm², corresponding at 60 r.p.m. to a rotational energy $\frac{1}{2}\, mv^2 = 95{,}000$ kgm. The magnitude of the torque (and current) which is required for the specified number of 24 reversals in one minute can be calculated thus:

If the diameter of the motor armature is D metres, and its peripheral speed v m/sec.,
the mass $\left(\frac{G}{9.81}\right)$ referred to the periphery m,
the speed n r.p.m.,
then the necessary power at the periphery for an alteration in speed is given by:

$$f = m \frac{dv}{dt} \text{ kg, but, as } v = \pi D \frac{n}{60}$$

$$= m \frac{\pi D}{60} \cdot \frac{dn}{dt}$$

and accordingly the torque

$$M = f \cdot \frac{D}{2} = \frac{\pi}{2 \cdot 60 \cdot 9.81} \cdot GD^2 \cdot \frac{dn}{dt} \text{ mkg}$$

$$= 0.00267\, GD^2 \cdot \frac{dn}{dt} \text{ mkg.}$$

Thus, when the speed is to be changed from + 60 to − 60 r.p.m. (that is to say by 120 r.p.m.) 24 times in 60 seconds, we have

$$\frac{dn}{dt} = \frac{2 \cdot 60 \cdot 24}{60} = 48 \text{ r. p. sec.}$$

and accordingly the required torque is

$$M = 0.00267 \cdot 190{,}000 \cdot 48 = 24{,}300 \text{ mkg}$$
$$= 24.3 \text{ mt.}$$

As the motor *can* develop a torque of 110 mt it is easily seen that the specified reversing speed can be given without any difficulty. It should in fact be possible to give not less than

$$\frac{110}{24.3} \cdot 24 = 109 \text{ complete reversals per minute.}$$

The above is naturally on the assumption that the reversing is perfectly smooth, and also that the operating gear for altering the field of the generator can be moved as rapidly. The magnetic field of the generator however also exhibits an effect corresponding to inertia, electro-kinetic energy ($\frac{1}{2}\, L\, i^2$, where i is the current strength in the field windings and L is the self-induction of the fields), which must undergo the same reversal as the motor ($\frac{1}{2}\, mv^2$). Or, while the rotational energy mv^2 of the motor is being altered from $\frac{1}{2}\, m\, (+v)^2$ to $\frac{1}{2}\, m\, (-v)^2$

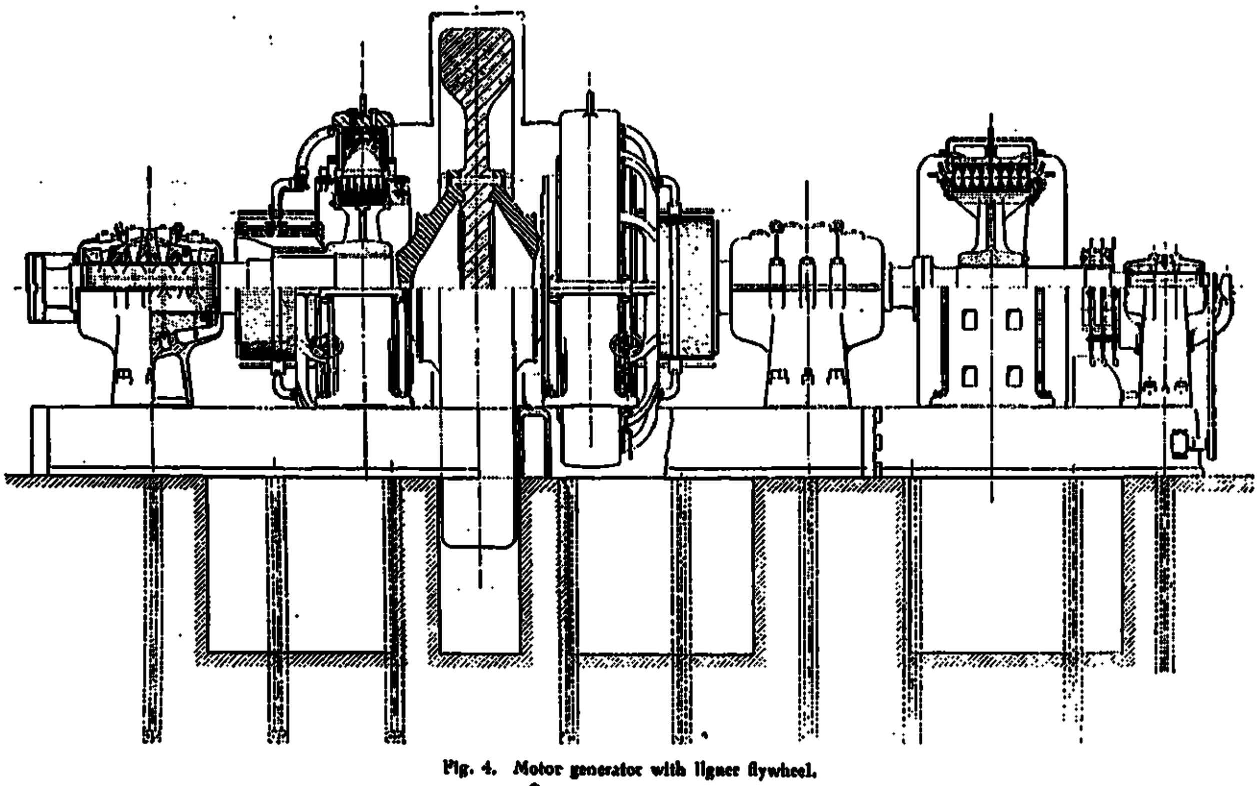


Fig. 4. Motor generator with Ilgner flywheel.

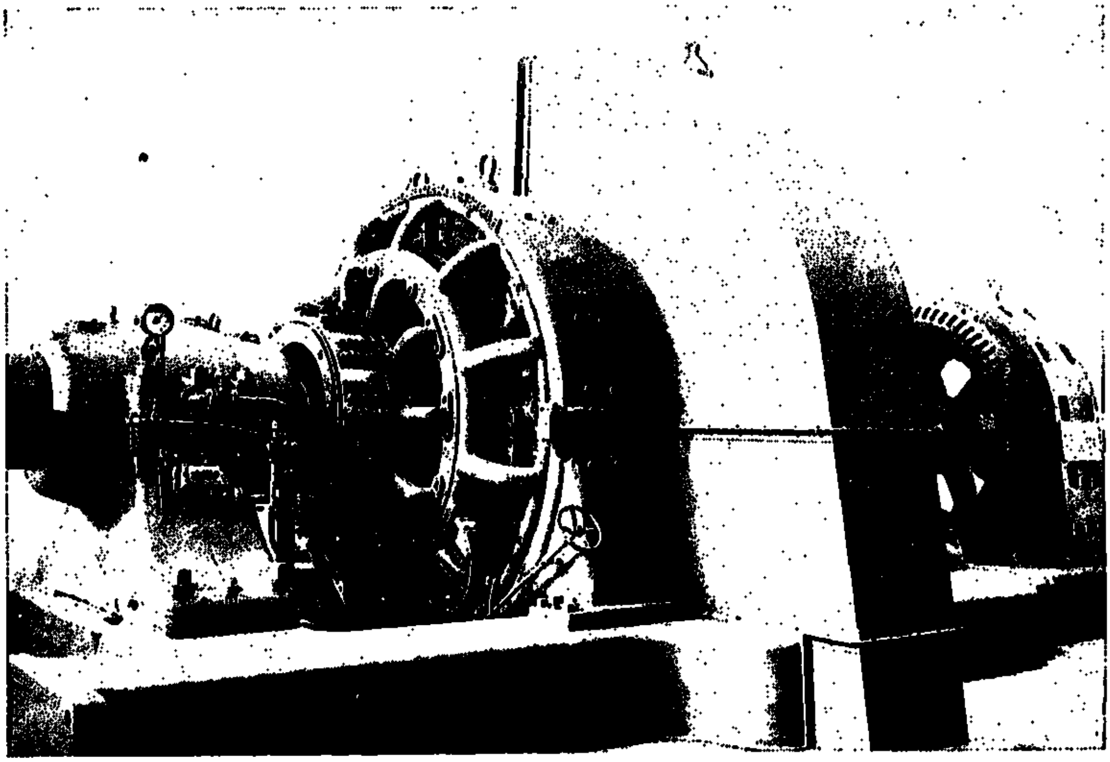


Fig. 5. Motor generator set with Ilgner flywheel.

the energy of the generator magnetic system Li^2 is being altered from $\frac{1}{2} L (+i)^2$ to $\frac{1}{2} L (-i)^2$. This change can no more be effected in an excessively short time than the former, and in this latter case the necessary electromotive power is in the same proportion to the rapidity of the change as the mechanical power (the torque) in the former case. In fact it is actually the lacking *emk* which in this case prevents such rapid reversing as the motor could otherwise withstand. On actual test it was found possible to effect 24 complete reversals in 46 seconds, which corresponds to a (constant) torque of $\frac{60}{46} \cdot 24.3 = 31.7$ *mt*. This torque further corresponds to a horse power at 60 r.p.m. of

$$\frac{31{,}700 \cdot 2\pi \cdot 60}{75 \cdot 60} = 2{,}660 \text{ h.p.}$$

As the normal output of the motor at 60 r.p.m. is 3,600 h.p. it is clear that the horse power corresponding to this speed of reversal is very far from overloading the motor. At the same time, under practical working conditions it has never been necessary to make use of such a high reversing speed. Assuming, however, that the motor is reversed 24 times in one minute, and that accordingly the torque of 24.3 *mt* is required, corresponding to an output at 60 r.p.m. of 2,040 h.p. or a mean value (since the speed is assumed to alter uniformly $\frac{dn}{dt}$ being constant) of 1,020 h.p. For each reversal the motor accordingly develops

$$A = 1{,}020 \cdot \frac{60}{24} = 2{,}550 \text{ h.p. secs.}$$

It might now be thought that these continual reversals to which the motor must be subjected require a corresponding power, namely not less than approximately 1,000 h.p., without any corresponding (useful) expenditure of power on rolling, or that electric drive of a rolling mill, on account of the great flywheel effect of the motor, must of necessity give rise to a correspondingly lower efficiency (than for example a steam engine drive). Such an assumption is, however, very far from being correct for the following reason. The torque of the motor is directed in the same direction during the whole of the reversal from + 60 to − 60 r.p.m., but since the power is the product of the torque and speed it follows that the power changes its sign as the speed passes through the zero, or in fact that the motor runs as a generator between + 60 and 0, and as a motor between 0

and − 60 r.p.m. With the generator these conditions are naturally reversed. During the former half of the time the generator runs as a motor and accelerates the flywheel, while during the latter half it again runs as a generator and retards the flywheel. The rotational energy of the motor itself is first transferred to the flywheel, and is afterwards returned again to the motor. If there were no losses in the generator, the motor, and the connections between them, the sum total of the necessary external energy for the actual reversing would be equal to 0. What is actually required is just that amount which corresponds to the losses referred to.

Motor Generator and Flywheel. The generator is, like the motor, a double machine (figs 4—5), and has to supply under all conditions the whole of the electric power required by the main motor. This does not only mean dealing with the current corresponding to full torque on the motor, but also the ability to supply this maximum current even when the strength of the field is weak, or reduced practically to nothing. The current strength which with full field on the motor gives a turning moment of 110 *mt* is not less than 6,500 amps. On the other hand the generator with full field gives 1,200 volts (600 on each half). The generator accordingly must be able to give as a maximum

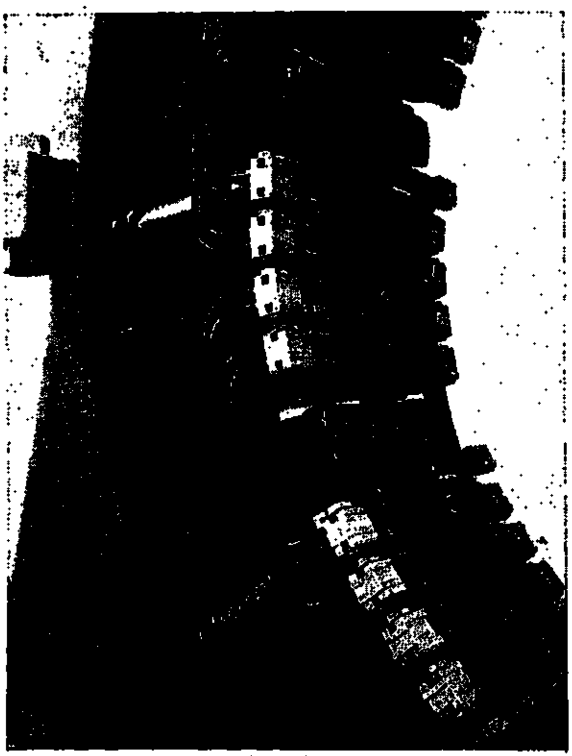


Fig. 6. Arrangement of field windings.

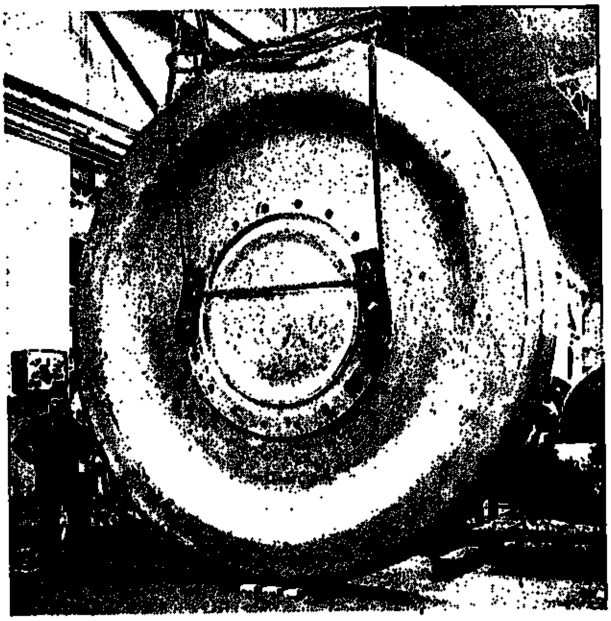


Fig. 7. Flywheel.

$$\frac{1{,}200 \cdot 6{,}500}{1{,}000} = 7{,}800 \text{ kW}.$$ It follows that the generator as well as the motor must be provided with the most modern arrangements as regards commutating poles and compensating windings, without which it would be quite impossible to adapt an electric motor to such a drive. Fig. 6 clearly shows the arrangements provided.

The Three-phase Motor. The three-phase motor is of usual design, 16 pole, and is supplied at 6,800 volts and 60 cycles, the synchronous speed being accordingly 450 r.p.m. The normal output is 2,500 h.p. (1,850 kW) and the maximum output is from 50—75 % greater. It is quite clear that only a small part of the mechanical power which the generator requires can be given by this motor; in fact the flywheel must assist continually during running.

The Flywheel. The construction of the flywheel and the method of supporting it is in accordance with figs 4 and 7. The outer diameter is 4.35 m and the peripheral speed accordingly at 450 r.p.m. not less than approximately 100 m/sec.

It is cast in Swedish steel in one piece and weighs 48 tons. On both sides stub axles are screwed by means of flanges of large diameter, and on the two axles the armatures of the generator are keyed one on each side (fig. 8). The flywheel with the two armatures is supported by two bearings, which are supplied with forced lubrication and water cooled. The flywheel is enclosed in a sheet steel casing to reduce the windage losses.

The total rotational energy of the motor generator set, of which the greater part is contain-

ed in the flywheel, represents at 440 r.p.m. 18,800,000 kgm, corresponding to 250,000 h.p./sec. or 51 kWh. To illustrate what this means it may be mentioned that with a speed

Fig. 8. Armature of generator.

drop of e.g. 15 % (to 375 r.p.m.) the set gives up due to the fall in speed only

$(1-0.85^2) \cdot 250{,}000 = 69{,}000$ h.p. secs. representing 6,900 h.p. for 10 seconds, supposing the speed reduction to be effected in this time.

On the other hand the three-phase motor requires an appreciable time to raise the speed again to 440 r.p.m. If for example the motor develops its full output 2,500 h.p. and if 230 h.p. are used up (the value actually obtained) in friction losses, then, assuming that the generator is unloaded and unexcited, the time required is

$$\frac{69{,}000}{2{,}270} = 30.4 \text{ secs.}$$

For starting from standstill, assuming that the three-phase motor develops its full torque corresponding to 2,500 h.p. at full speed, the time required is no less than

$$\frac{250{,}000 \cdot 2}{2{,}270} = 220 \text{ secs.} = 3.7 \text{ minutes, which}$$

accordingly is the shortest time in which the set can be started without overloading the motor.

Regulation of Output. In order that the flywheel may perform its function as a buffer for the large variations in power required by the mill, and enable a uniform amount of power to be taken from the supply, the speed of the three-phase motor must be variable and elastic. This characteristic is obtained by having an automatically variable resistance in the rotor circuit of the motor. The resistance itself, which is shown in figs. 9 and 10, is a liquid resistance. It consists of a large container filled with a solution of soda in which movable plates (electrodes) dip, and which are connected to the sliprings of the motor. The deeper these plates

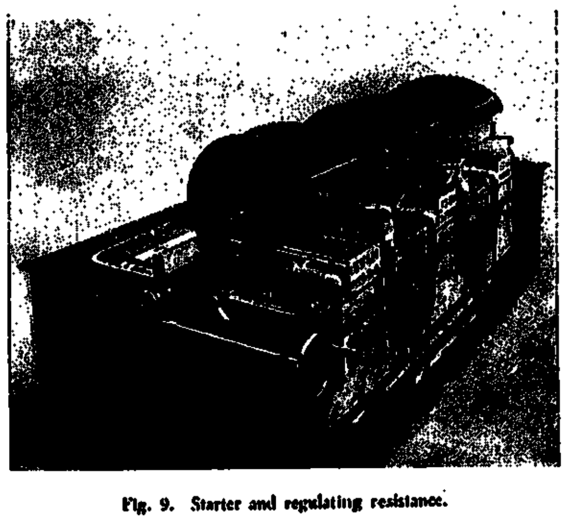


Fig. 9. Starter and regulating resistance.

are immersed in the solution the lower becomes the resistance and vice versa. The position of the plates is controlled by an induction regulator which in its turn is excited proportionally to the power taken from the network. The principle of this regulation is shown best in fig. 1.

In this manner the arrangement exerts itself to maintain the demand on the network at a constant value in spite of the heavy and sudden load variations caused by the rolling.

Control Apparatus. The control of the rolling mill motor is ideal in its simplicity. Certainly the details of the arrangement are not altogether so simple as shown in

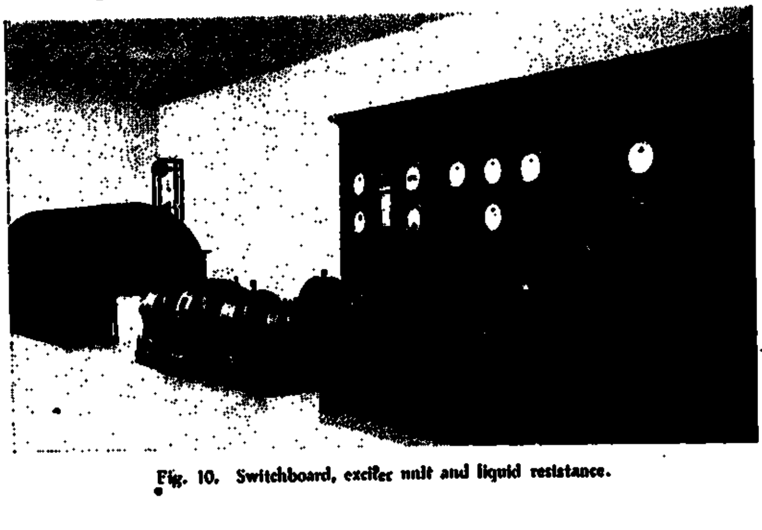


Fig. 10. Switchboard, exciter unit and liquid resistance.

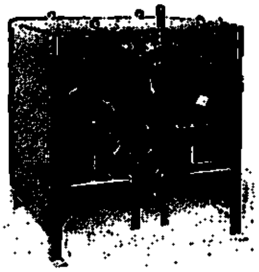


Fig. 11 a. Control apparatus, front view.

the diagram (fig. 1), but the work which the driver has to perform is not itself more complicated than can be gathered from this drawing. The control handle does not regulate the field current of the DC machine direct, but generator and motor each have their own exciters which are themselves separately excited, and the regulation is carried out in the field circuits of these. In order to obtain the least possible time constant (dead point) in the control, non-inductive resistances are used in the field circuits of both the main machines and exciters. By the help of these details and the refinements in the construction of the machines themselves, it has been made possible to obtain the reversing frequency which has been previously referred to.

The general appearance of the control apparatus is shown in figures 11 a, b and c, the last shows also the instrument pillar supporting instruments for reading:

The voltage, current and speed of the rolling motor,

The speed of the motor generator set,

The output of the three-phase motor.

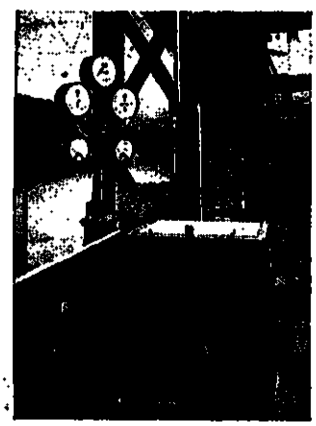


Fig. 11 c. Control apparatus and instruments.

It might seem that it would be very exacting to control the rolling mill while reading so many instruments, particularly as they are all very sensitive to the smallest movement of the control handle, and do not move to the same extent or even in the same direction. What may seen complicated in theory, however, is in this case quite simple in practice, and actually the driver does not take particular note of the instruments except to observe that everything is as it should be. If anything should occur (for example overload, or a fault in any of the machines) the matter is dealt with entirely automatically, the whole of the machinery gradually coming to a standstill, it being only possible to start it again after the fault has been cleared.

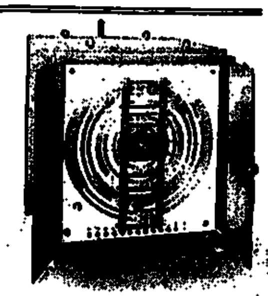


Fig. 11 b. Control apparatus, rear view.

As long however as everything is in its customary order the motor and the rolling mill are under perfect control of the driver, and it is quite astonishing with what ease and precision he is able to start, accelerate and stop the motor, and adjust its speed to suit the dimensions of the ingot being handled during different phases of the rolling.

II. TESTS MADE ON THE INSTALLATION.

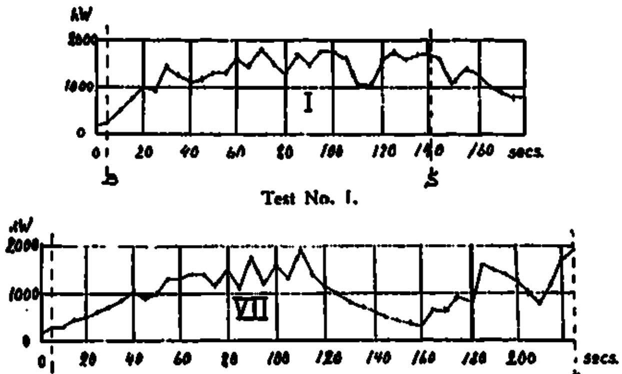
Inspection Tests. On setting the installation to work and before erection, the usual tests for electrical machines and apparatus were carried out. The results of these tests have already been to some extent referred to; we need only mention here the overspeed test on the motor generator unit and flywheel, and determination of the excitation of the various machines, checking of efficiencies etc. The flywheel was guaranteed to withstand an overspeed of 25 % above 450 r.p.m. *i.e.* 560 r.p.m. On test the speed was successively increased, while precision measurements were made of the dimensions of the wheel in different directions to determine if any permanent deformation took place. Nothing of this sort was discovered up to the maximum speed.

As regards the efficiency of the machines, this was arrived at by taking measurements of the separate losses in accordance with table I below.

Running Tests. The installation ran in a perfectly satisfactory manner from the time it was started up, but in order to obtain more definite information regarding the work which the machines and apparatus were called upon to perform in practice than the ordinary instruments were able to supply, an opportunity was taken during the autumn following handing over to make special electrical measurements while rolling was in progress. Accordingly a reading was taken of the three-phase power supplied every five seconds, while at the same time the speed of all machines was determined by a recording tachograph. For the rolling mill motor speed a further tachograph was used, while the voltage and current supplied by the DC generators was registered by an oscillograph.

Such tests were carried out on seven special rolling periods. The working of the rolling mill itself during these seven tests is shown in Table II herewith..

For the electrical conditions only two tests were taken namely test No. 1 and test No. VII, of which the first covers rolling with the girder rolling mill alone, and the latter rolling with the ingot mill alone. In figs 12—15 are shown curves for (1) the primary three-phase power, (2) the speed of the flywheel, (3) the speed of the rolling mill motor, and (4) oscillograms of the DC voltage and current for both these characteristic rolling conditions. Comparing figs 12 and 13, a great similarity will be noticed except that one appears to be approximately an upside down view of the other. If fig. 12 had been made by a recording instrument in stead of being constructed from a number of separate readings, the similarity would be still greater. This similarity is explained by the fact that the regulating resistance of the three-phase motor was adjusted so as to commence regulation with a load of approximately 2000 kW. Up to this power requirement the rotor resistance was constant, and accordingly the slip was nearly proportional to the load, and in a corresponding degree the curves are copies of one another.



Test No. I.

Fig. 12 a & b. Power taken from network by three-phase motor. Test No. VII.

Fig. 13 a. Speed of flywheel. Test No. I.

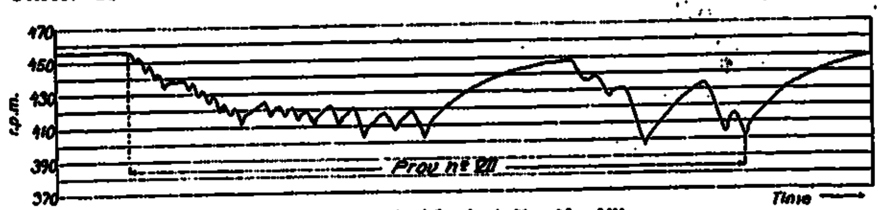


Fig. 13 b. Speed of flywheel. Test No. VII.

Table I.

	Load	Output	Efficiency %	Power Factor
Three-phase motor of motor generator set	1/1	2,500 h.p.	94.7	0.88
	1/2	1,250 h.p.	94.0	0.87
DC generator	1/1	2,880 kW	92.6	
Rolling Mill motor	1/1	3,600 h.p.	92.4	

As regards the recorded curves and oscillograms a similar likeness can be established between the voltage curve (marked v on the oscillograms) and the speed of the motor (fig. 14), if one takes note of the difference in the time scale in the two cases. This is what would be expected to the degree which the speed of the motor is varied by altering the voltage of the generator only (and not by field regulation of the motor itself). It further leads one to note that the strength of the current (marked a in the oscillogram) to a certain extent depends on the slope of (tangent to) the speed curve of the flywheel; it should especially be observed how the heavy negative current peaks during reversal of the motor make themselves visible by a considerable rise in the flywheel speed curves. In this connection it may be mentioned that the current curve shows that the driver has carried out reversing unnecessarily quickly, with the result that the current taken on reverse is high and reversing completed as a rule long before it need have been. With a less hurried reversal the stresses and losses would be less than those which are shown here to be actually the case.

Quantitative Results of the Readings. In order to arrive at the main factors which determine the power requirements during rolling of this kind, we have made a number of calculations and deductions from the readings obtained.

We have integrated the curves in figure 12, *i.e.* determined the gross power output for each rolling period reckoned at the supply to

Table II.

Test No.	Time of starting first pass	No. of secs. to completion of final pass.	Billet's Dimensions Before Rolling	Billet's Dimensions After Rolling	Billet's Weight kgs Before Rolling	Billet's Weight kgs After Rolling	No. of Passes
I	1h 3m	136	2×2×56 dm	430 dm U-balk 260	—	c:a 1630 kg	11
II	1h 9m	—	2×2×56 dm		—	—	—
III	1h 22m 30s	196	4.5×5, 5×15 dm	1×1×340 dm	c:a 2700 kg	c:a 2600 kg	23
IV	1h 31m	127	2×2×56 dm	430 dm U-balk 260	—	c:a 1630 kg	11
V	1h 33m 30s	144	4.5×5, 5×15 dm	2×2×88 dm	c:a 2700 kg	—	—
VI	7h 23m	190	4.5×5, 5×15 dm	1×1×340 dm	c:a 2700 kg	c:a 2600 kg	22
VII	7h 30m	221	4.5×5, 5×15 dm	1×1×340 dm	c:a 2700 kg	c:a 2600 kg	22
VIII	7h 35m	150	4.5×5, 5×15 dm	1.8×1, 45×33	c:a 2700 kg	—	19

the three-phase motor. With this we have also included the energy which the motor required to bring the flywheel back to its normal speed after the last pass of the rolling period. This energy expressed in kWsecs. is given in the first column of table III.

From the oscillograms in fig. 15 we have obtained the power by multiplication of the voltage (v) and the current (a); the curve thus obtained has further been integrated, and in this way the energy obtained which was supplied to the rolling mill motor. How the power alters during the pass, reversing and standing periods is in accordance with fig. 16, in which we have assumed a somewhat idealised form for the voltage and current curves.

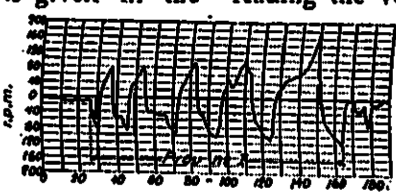


Fig. 14 a. Speed of rolling motor. Test No. I.

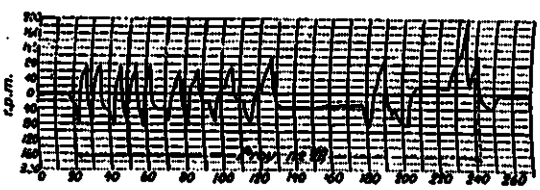


Fig. 14 b. Speed of rolling motor. Test No. VII.

The values are given in column 2 of table III. The difference between the values in the first and second columns depends on the losses in the motor generator set and flywheel, and are accordingly dependent among other things upon the relative length of pass and pause. In test VII the effective time of pass came out at approximately 29 % of the total time, and in test I approximately 38 %. To some extent this explains the large difference between the energy taken and supplied by the motor generator unit during test VII in comparison with test I. Another consideration which may have some effect is of course the difficulty of accurately reading the voltage and current on the oscillograms, where the scale is so small and the "lines" so thick. The relation between the two values is given in column 3 of the same table, and has there been called the "efficiency" of the motor generator set. This must be a little wanting in true significance and must be used with care, so that it does not give rise to any misunderstanding, attention being paid to the want of accuracy in the values which has been pointed out.

We have lastly compared the values found with other values which are accessible, and with data calculated for the nett energy required for the rolling itself.

J. Puppe has, in his classical treatise on power requirements in rolling, fixed a coefficient, k, which is the relation between the altered volume during the pass (V_{mm^3}) and the necessary work for this (E kgm)

$$\text{Accordingly } k = \frac{V}{E}$$

Table III.

Test No.	kWsecs. to Three-phase Motor	kWsecs. to Rolling Motor	"Efficiency" of Motor Generator Set.	kWsecs. for rolling	Total "Efficiency".
I	221,000	181,000	c:a 0.8	(x = 1.38) : 126,400	c:a 0.6
VII	269,000	151,200	c:a 0.6	(x = 0.4) : 125,500	c:a 0.5

Fig. 15 a. 1.

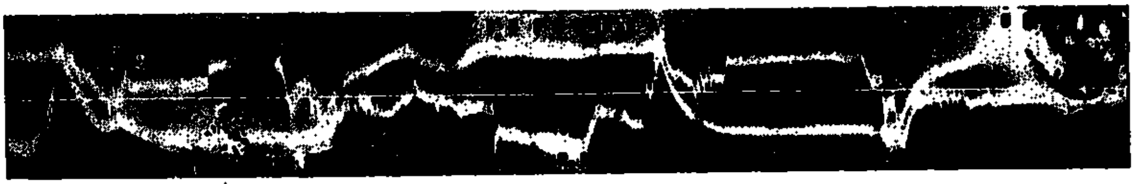


Fig. 15 a. 2.

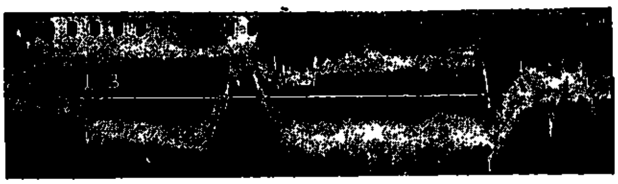


Fig. 15 a. 3.

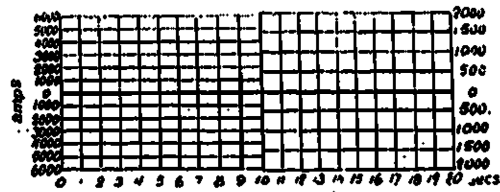


Fig. 15 a. 4.

Voltage and current at the rolling motor. Test No. I.

Fig. 15 b. 1.

Fig. 15 b. 2.

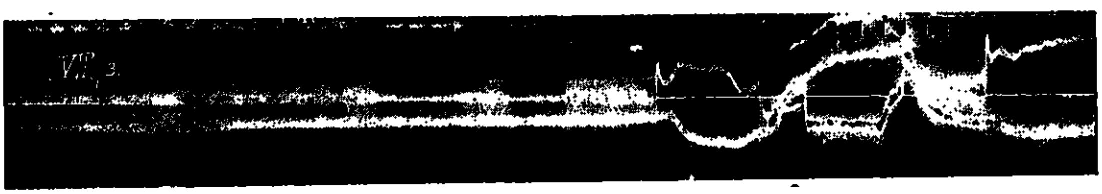


Fig. 15 b. 3.

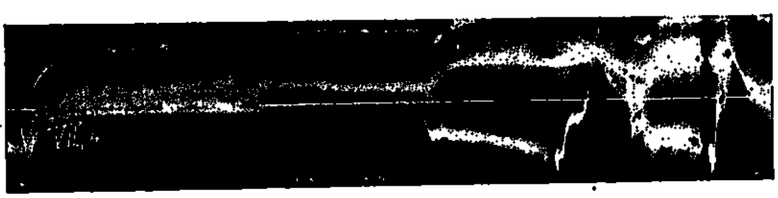


Fig. 15 b. 4.

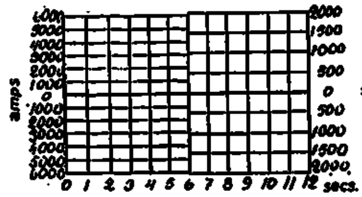


Fig. 15 b. 5.

Voltage and current at the rolling motor. Test. No. VII.

Table IV.

Test	Gross kWh per ton nett	Average rolling time per billet, seconds	Pause, seconds	Gross rolling time, seconds	No. of billets per hour	Nett tons rolled per hour	Gross kWh per hour
I	38	132	60	192	18.7	30.5	1,160
VII	29	202	60	262	13.8	36	1,040

Following from this coefficient and other values he gives as a result of determinations from tests on several reversing rolling mills, we have found another coefficient, $\varkappa$, which gives an expression for the necessary torque during rolling a function of the cross section of the billet and the percentage increase in length. Regarding this matter it would take up too much room to go through all the calculations and data by which the expression in question was arrived at; it is enough here to give the formula:

$$M = \varkappa \cdot a \cdot d$$

where
- M is the necessary torque for rolling in mt,
- a is the cross sectional area of the billet after pass in dm^2
- d is the percentage elongation during the pass
- $\varkappa$ is a coefficient.

As regards $\varkappa$, we have found that this has the following simple relation to the constant k referred to above, namely $k \cdot \varkappa = 40$, from which it follows that $\varkappa$ depends upon the temperature of the billet in the same manner (although inversely) as k.

From the reduction program a and d for each pass are known, and accordingly — if (the temperature and) $\varkappa$ is known — the torque M can be found. If, further, we let n denote the mean value of the r.p.m. of the rolling mill motor during the pass, and t the time (in seconds) which the pass occupies, the work done in rolling during a pass is given by

$$A = \frac{2\pi}{60} \cdot 9.81 \cdot \varkappa \cdot a \cdot d \cdot n \cdot t$$

$$= 1.03 \cdot \varkappa \cdot a \cdot d \cdot n \cdot t \text{ kWsecs.}$$

For ingot rolling (test VII) where chiefly only so-called "direct" pressure occurs, and where the temperature of the billet should be somewhere about 1,200° C we have taken $\varkappa = 0.4$ and found

$$\Sigma A = 125{,}500 \text{ kWsecs.}$$

For girder rolling (test I) where the temperature is lower, and where "indirect" pressure takes place we have, chiefly by the help of Puppe's figures, assumed $\varkappa = 1.38$ and found

$$\Sigma A = 126{,}400 \text{ kWsecs.}$$

These values are given in the fourth column of table III, and lastly from these a total "efficiency", has been calculated and included in the fifth column.

It is of course not claimed that these figures are quite accurate or applicable in all cases, but at the same time it can be stated that the value which from various points of view has been given to the coefficient $\varkappa$ is not very far from correct, and also that the whole arrangement has approximately the total "efficiency" which had been anticipated.

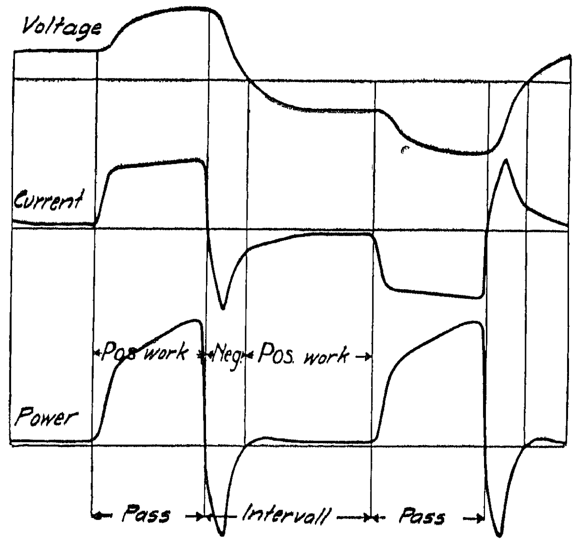


Fig. 16.

Lastly we have calculated the production of the rolling mill on the assumption that the rolling is carried out as it was in the two cases, I and VII, rolling each time only taking place in the one mill. A pause of one minute has also been assumed between rolling periods, which time has been found ample for the flywheel to accelerate to its maximum speed with this kind of rolling. The results are given in table IV and should be clear without further explanation:

The last column gives the average power taken from the supply by the three-phase motor.

It may be remarked in conclusion that these figures do not claim to show how the rolling will come out as regards production under all conditions, but only demonstrate the behaviour in this respect with the kind of rolling which was undertaken during this investigation, with the assumptions which we have made, and with certain reservations regarding accuracy.

CURRENT ILLUSTRATIONS.

Interior from the exhibition of modern electrical machinery and apparatus in Asea's head office at Vesteras.

Interior from Asea's museum, in which are preserved specimens of the older machine types etc.

Vesteras 1925 Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

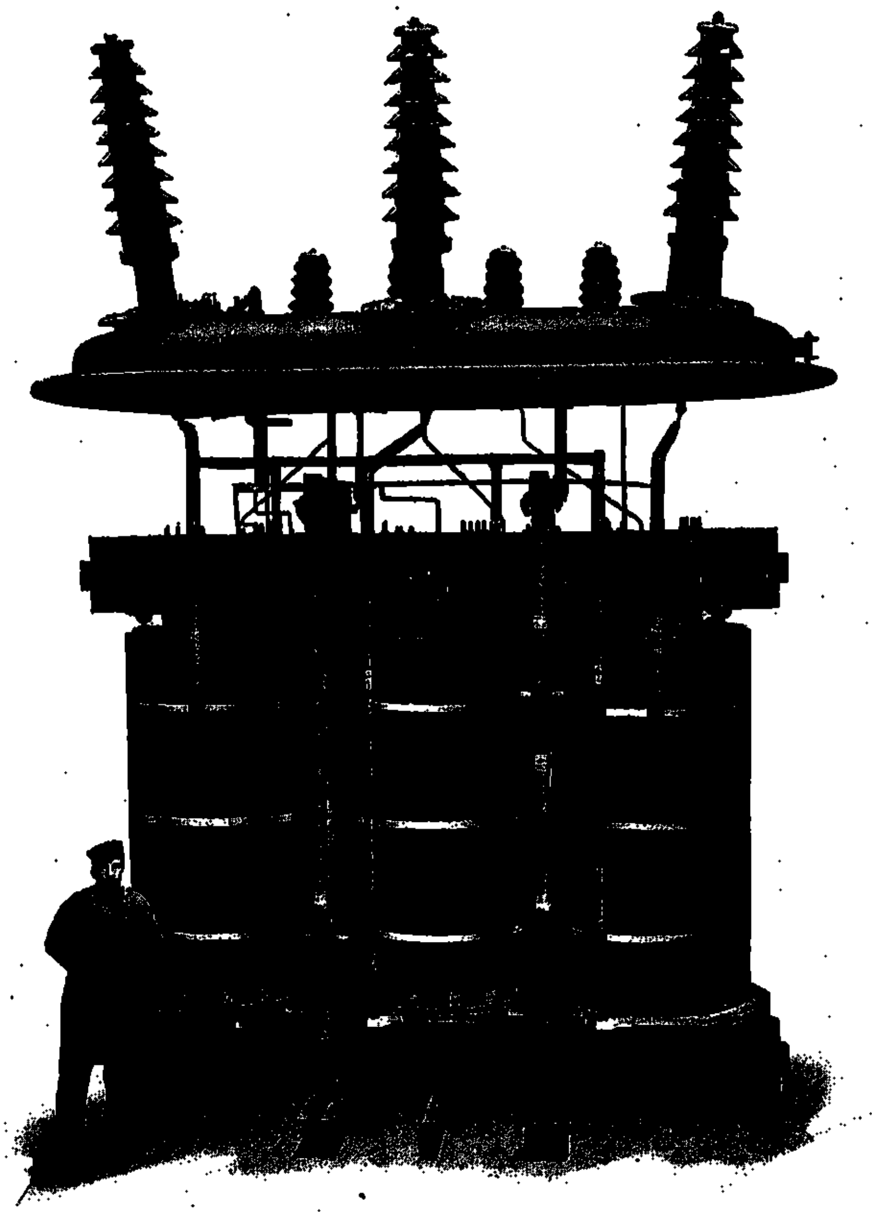
ALLMÄNNA SVENSKA ELEKTRISKA A.B.
VESTERAS — SWEDEN

SWEDISH GENERAL ELECTRIC LTD
5, CHANCERY LANE—LONDON

VOL. II
1925

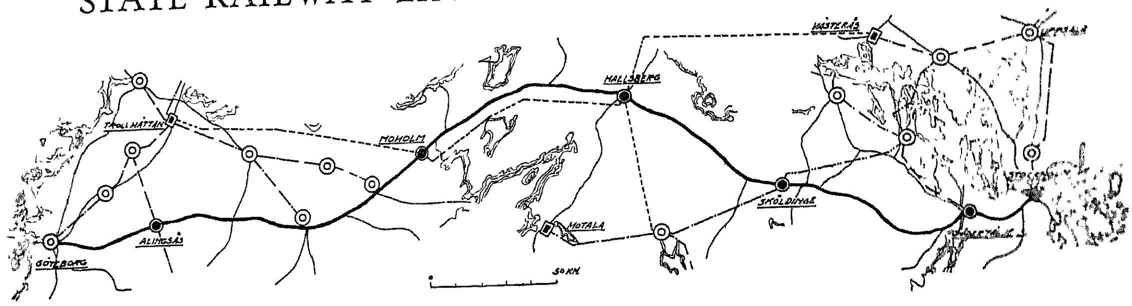
All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesteras, Sweden.
Permission is given to reprint articles or extracts from this journal, on condition that the name — Asea-Journal — is clearly stated.

OCTOBER
No. 10



7,000 kVA three-phase transformer 220/22/6.6 kV, the first transformer ever built in Europe for this voltage. Installed in a sub-station on the railway line Stockholm—Gothenburg, Sweden.

TRANSFORMERS FOR THE ELECTRIFICATION OF THE SWEDISH STATE RAILWAY LINE STOCKHOLM—GOTHENBURG.



.... Trunk power line 120,000 volts
—.—. 50,000 and 40,000 volt power lines
—..— 70,000 volt power line
Waterfalls Board power station
Waterfalls Board transformer sub-station
Railway sub-station

Fig. 1. Map of the railway line Stockholm—Gothenburg.

1. *Stationary Transformers.*

The section of the railway between Stockholm and Gothenburg is being supplied from five main sub-stations, to which the Swedish Waterfalls Board are supplying energy in the form of high tension three-phase current. The pressure in these stations will be transformed down to lower voltages suitable for supplying the transmission lines for the railway in their own neighbourhood, and also for distribution to the farms and estates surrounding them. Two of the stations, namely those at Sodertelje and Skoldinge, are supplied from Alvkarleby at 70 kV and for transforming down, existing transformers previously supplied by Asea, are being used. As these particular transformers are of older type, they will not be dealt with here and we shall confine ourselves to the new plant being supplied by Asea especially for this electrification. The three remaining stations, namely those at Hallsberg, Moholm and Alingsas are supplied from the State Power Station at Trollhattan, the two first-named via the main western transmission line and the last by a special direct line. For these stations Asea is at present building all the transformers which are as follows:

Moholm: Two TCOS 79, 7,000 kVA, 132/22 6.3 kV, $\triangle/Y_0/\triangle$, 50 periods.*)

Hallsberg: Two TCOS 84, 10,000 kVA, 132/77/6.3 kV, $\triangle/Y_0/\triangle$, 50 periods.

Alingsas: Two TCOS 84, 10,000 kVA, 132/55/6.3 kV, $Y_0/Y_0/\triangle$, 50 periods.

All transformers are accordingly provided with three separate windings, each designed to carry the full output, and of these the 6.3 kV winding is used for supplying the railway converter sub-stations and the intermediate voltage is used for local distribution. All transformers are of the core type, cooled by oil circulation and suitably designed for out-door erection. As we have so far given no description of the large modern Asea transformers, the construction of these will be briefly explained.

The Core. Fig. 2 shows the present standard arrangement, adopted by Asea, for large three phase core types. The core, even for the largest sizes, is built

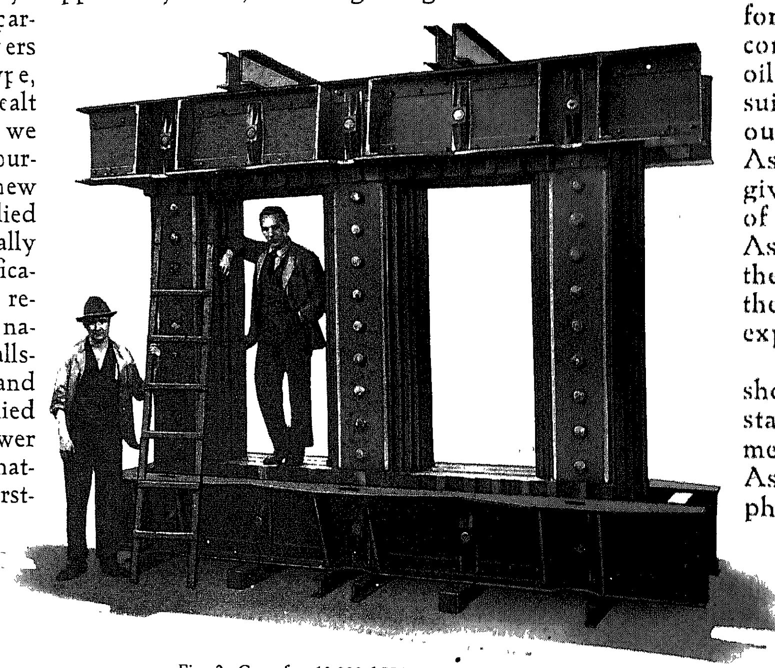


Fig. 2. Core for 10,000 kVA, 50 cycle transformer.

*) Y_0 denotes Y-connection with neutral point brought out.

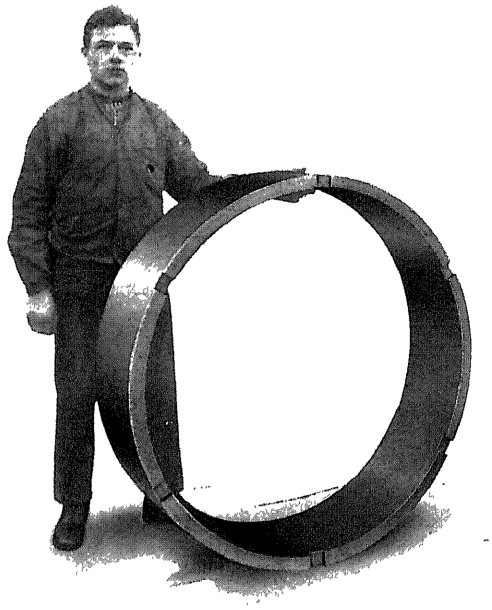


Fig. 3. Bakelite ring for use between H.T. winding and yoke.

with interleaved joints, which construction has been shown to have usually many advantages over the loose yoke pattern. If the core is built with one or both of the yokes butt-jointed to the limbs it is obvious that the joints between limbs and yoke must, for mechanical reasons, be carefully machined, and it is not possible to prevent the insulation between the separate laminations being damaged, so that these are partially short circuited and under all conditions this gives rise to increased iron losses. The cooling of large cores introduces many difficulties in any case, and we have considered it unsatisfactory to increase them in this unnecessary manner. There is also danger that these partial short circuits may extend, due to the laminations welding themselves together, and if this should happen it is only a question of time before the whole core is ruined. A number of foreign firms who have continued to work with the loose yoke are

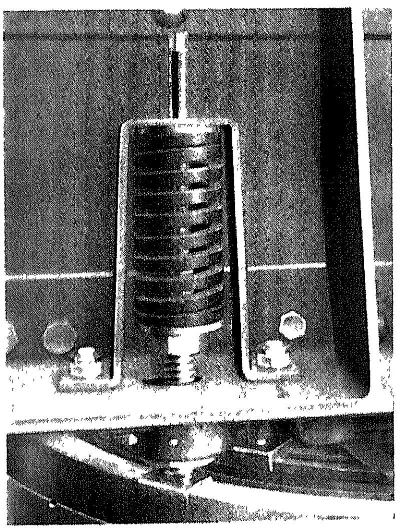


Fig 4. Asea automatic coil shrinkage clamping device.

arranging special cooling ducts at the joints in order to prevent the spreading of the short circuited spots by the provision of extra cooling at these points. It appears to us, however, that in this way the problem is being attacked from the wrong side. Even when the machining referred to at the joints is done with the greatest care, great difficulties have arisen in making the cores silent during working, and in this respect also the interleaved joints adopted by us offer a considerable advantage. To make the cooling easier on large units the cooling surface of the limbs of the transformer cores is increased by grooving the side surfaces, the grooves being

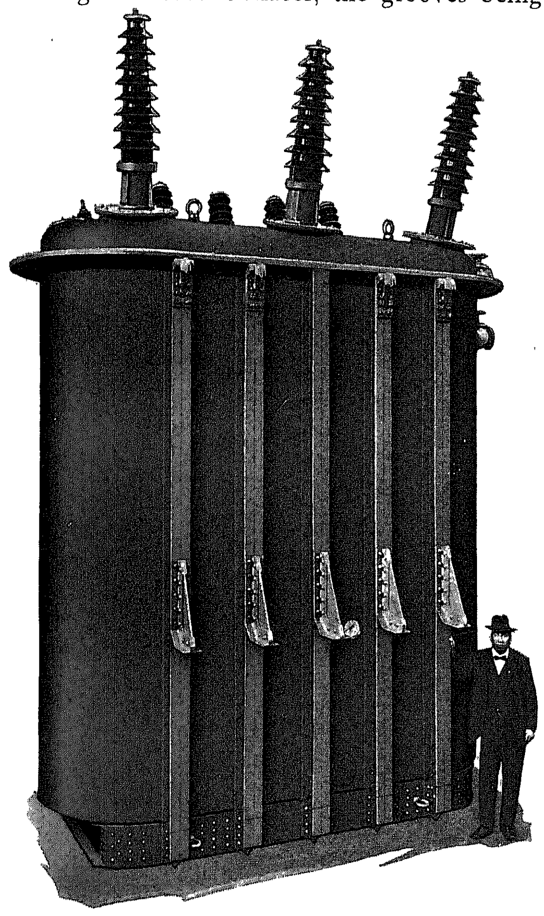


Fig. 5. Exterior of TCOS 79, 7,000 kVA, 132/22/6.3 kV, 50 cycles.

provided by cutting the core plates of different widths. In this way cooling corrugations are obtained, the appearance of which can be gathered from fig. 2. In particularly large units this design is also used for the upper and lower surfaces of the yokes. In other transformers the cores are normally divided up into several stacks of plates divided from one another by oil ducts. The assembly of the core is made as simple as possible by using a few heavy

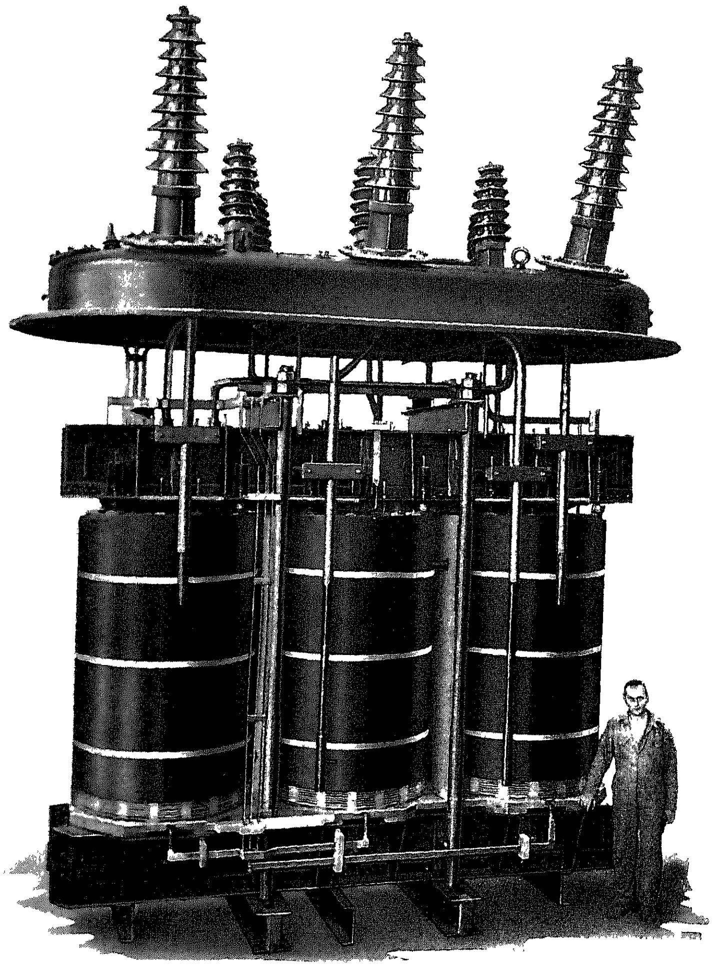


Fig. 6. Interior of TCOS 84, 10,000 kVA, 132/77/6.3 kV, 50 cycles.

case the circuit so obtained is not traversed by any flux, so that the current induced in the short circuited path is theoretically zero. To lay great weight on this point, as a number of firms do, hardly seems correct to us, because the bolts near to where the core joins the yoke cannot be so placed that the principle referred to above is followed out, since the field must run here more or less sideways, and in addition no great difficulty in effectively insulating the bolts exists with the low voltages which occur, assuming that the mechanical design of the various details used is good. A construction which allows the risk of a short circuit between these vital parts must be considered very inferior in consideration of the ease with which sufficient insulation can be arranged.

The windings. With the pressures which are in question here the transformers are, without exception, provided with cylindrical windings *i.e.* with the windings for the different voltages placed concentrically and, in general, with the winding for the lowest pressure nearest the core. The 6.3 kV windings consist of one coil per leg and are spirally wound, the group of conductors being spirally wound in a single layer. Oil ducts are arranged between the turns of the winding, and these ducts are maintained by placing distance pieces of presspahn at frequent distances along the coil. It is clear that such a coil is particularly effectively cooled since the heat can be conducted away from all four sides of each conductor. The arrangement also increases the strength of the insulation between

bolts rather than a large number of smaller ones. In this way all the necessary details for insulating the bolts, such as bakelite tubes, washers, etc. are of such dimensions that they can be easily handled and assembled with ordinary care without any risk of short circuits developing between the bolts and the core. The arrangement of the bolts in a single row may also be considered advantageous from the point of view of the possibility of two bolts, lying one above the other, coming in contact with the iron core, since in such a

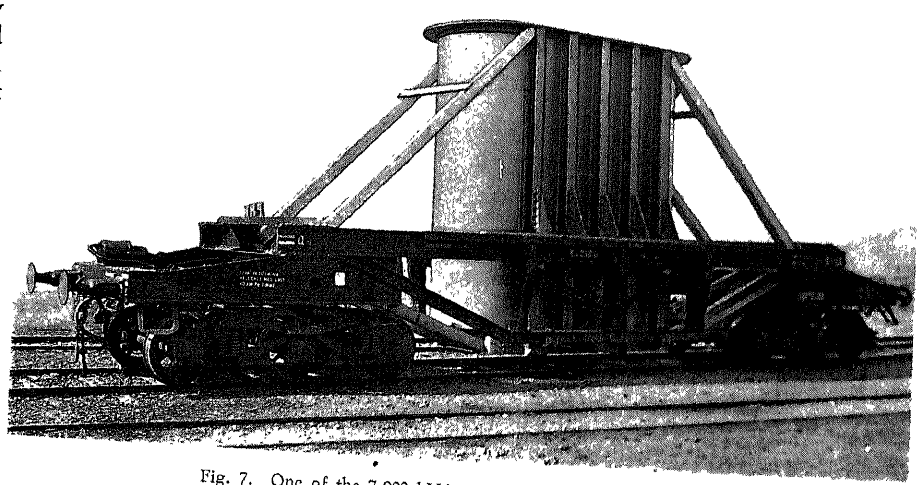


Fig. 7. One of the 7,000 kVA transformers leaving the works.

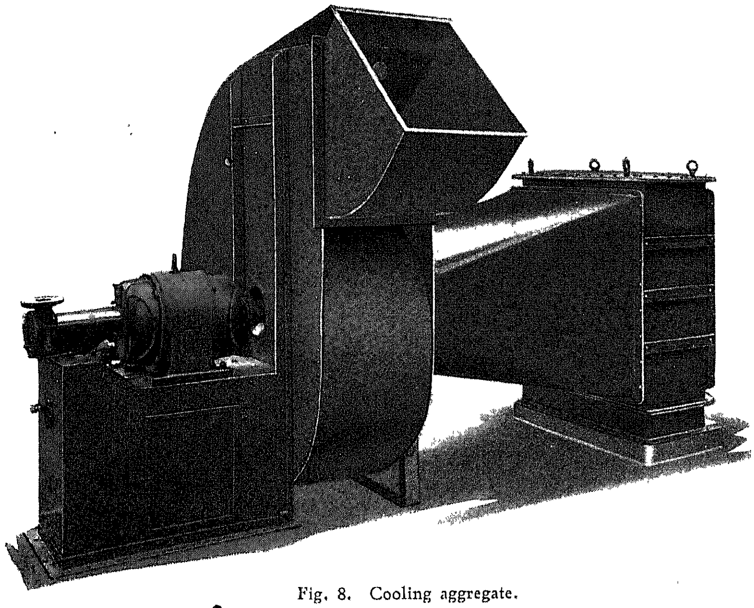


Fig. 8. Cooling aggregate.

direction. The voltage between two adjacent conductors can, with flat coils, only reach the voltage induced in one turn, while on the other hand in layer-wound coils this is many times greater, depending on the number of turns per layer. With regard to cooling, the flat coil type has the great advantage that each separate turn of the coil is directly cooled by the oil. Lastly, by no means the least advantage it that during, and after manufacture, each separate turn is available for inspection, while the construction of layer-wound coils in many ways prevents proper control of the progress of the work. The insulation between turns consists of a combination of paper and cotton, which, on the high tension conductors especially, is made particularly heavy, and as an example it may be mentioned that on the transformers for Moholm the sectional area of the copper amounts only to 25 % of the cross sectional area of the insulated conductor. The coils are twice subjected before assembly to vacuum impregnation with oil resisting varnish, and by this means, after drying, they are particularly rigid and stable mechanically. The mechanical strength of the coils was made the subject of an investigation by the Swedish State Testing Bureau, when an ultimate compressive stress of approximately 50 kg per cm^2 on the surface of

neighbouring turns. To reduce the eddy-current losses each conductor is split up into a large number of parallel sections consisting of thin copper strip in the radial direction, and the separate sections of the conductor are transferred successively so as to change places in the conductor group. The coil is wound direct on a seamless bakelite cylinder which acts at the same time as a mechanical support for the winding which it insulates from the iron core. Windings of this kind are relatively broad, which is a great advantage with regard to mechanical stability, as the surfaces transmitting pressure between the various turns are large, and the supporting rings between the ends of the winding and the yokes can also be of great width. As these rings are made in the form of massive bakelite cylinders, particularly strong supports are obtained against the yoke in the axial direction.

The windings for the medium pressure, on account of the higher voltage, are of different construction, and these are made on the same principles as the high tension windings. All these windings are made in the form of flat coils, the separate coils being wound of flat copper strip arranged like the turns of a clock spring. These windings have been found better than any other type for higher voltages. Among other advantages it may be pointed out that short circuits between turns in the same coil cannot occur, as in the case of coils wound in layers, which are also inferior in the mechanical respect, since the insulation on the conductors is easily destroyed on short circuit under the action of the pressures which occur in the axial

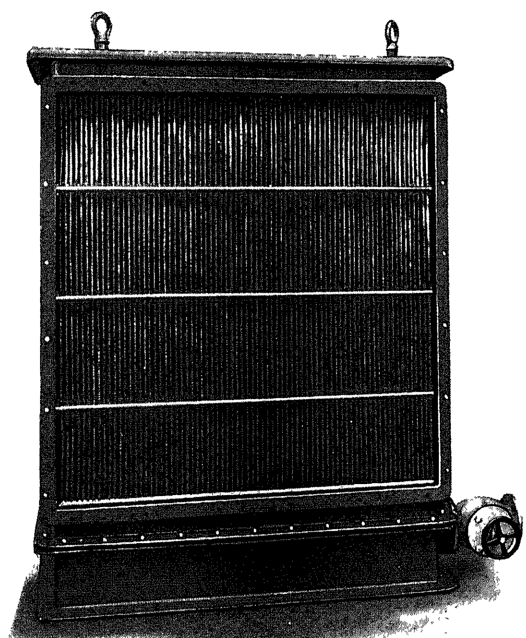


Fig. 9. Oil cooler for 7,000 kVA transformer.

the coil was measured when compressing the coils in the axial direction. As the total surface area of the presspahn collars between the coils is about 850 cm^2, a limit of compression for the windings is accordingly obtained amounting to 43 tons, a figure which is five times as great as the strains to be expected on the windings in the axial direction when the worst short circuits occur.

The windings are insulated from one another by a large number of bakelite cylinders which divide the insulation space into a large number of electrically series connected oil ducts. With the voltages now in question the insulation to iron naturally gives rise to great difficulties, and in order to improve the insulation round the high tension windings special precautions are taken in this case at their ends. Tests made with specimens have shown that these arrangements are able to withstand a test voltage exceeding the guaranteed test voltage of 275 kV by 50 %, without any trace of brush discharge or other damage to the material being detected. Against the yoke the windings are supported, like the low tension windings, by clamping rings in the form of thick bakelite cylinders, which in order to obtain a strength commensurate with the strength of the windings, themselves, and the stresses occurring, are amply dimensioned as shown in fig. 3. On these rings a number of clamping screws press, arranged in the upper channels of the yoke, their function being to fix the position of the coils in the axial direction so that they cannot be forced up against the yoke under the action of short circuit stresses. Windings for specially high voltages contain a great deal of insulating material, and on this account there is a risk of the winding settling down, due to the vibration occurring on load after the clamping screws have been tightened up. This leads to a certain amount of play between the windings and the upper yoke, and on this account the coils are free to rub against one another when vibration takes place and the rigidity is wanting which is necessary to resist the strains occurring on short circuit. The common hand-operated screws are accordingly replaced on the high tension windings by an automatically acting arrangement, fig. 4, con-

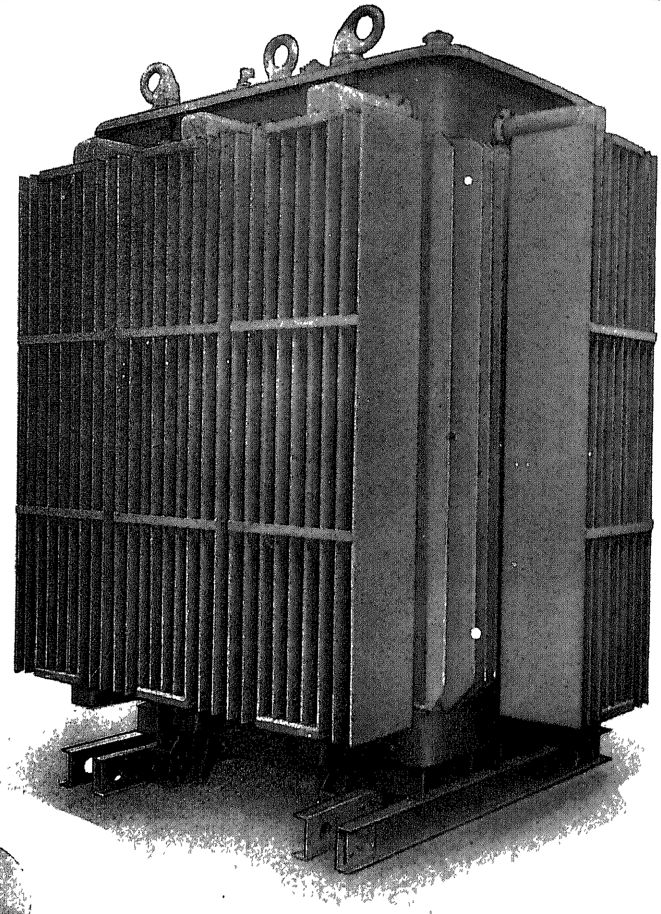


Fig. 11. Exterior of EO 77, 2,400 kVA, 3,000/16,000 volts, 16⅔ cycles.

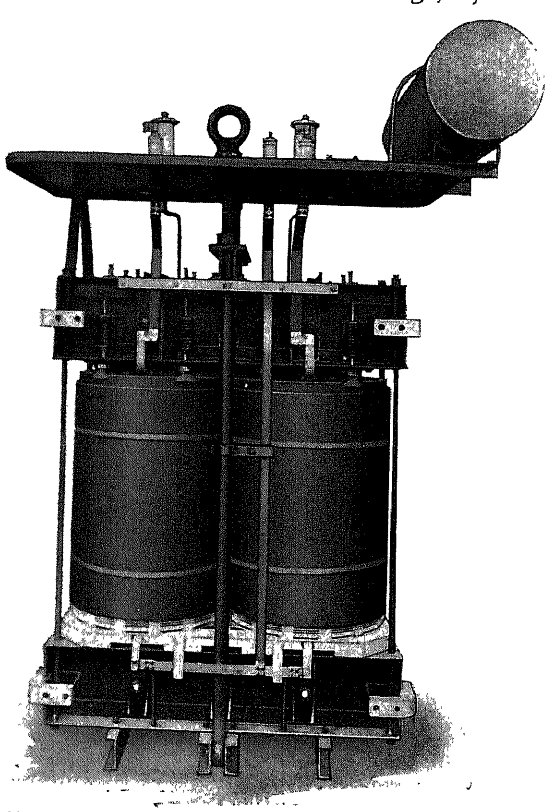


Fig. 10. Interior of EO 77, 2,400 kVA, 3,000/16,000 volts, 16⅔ cycles.

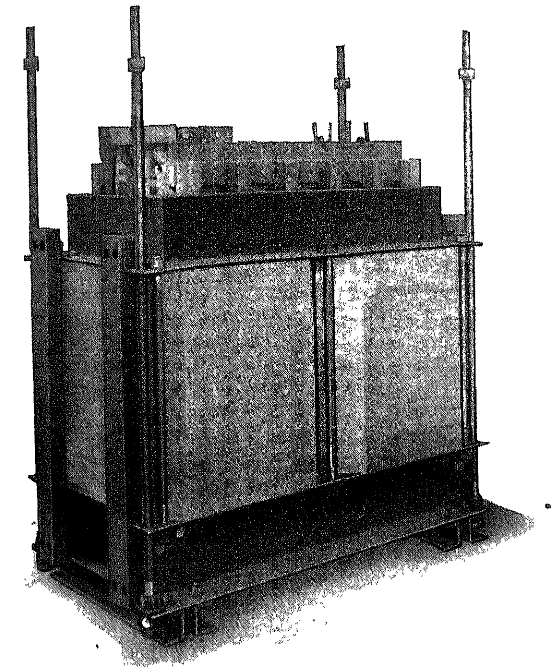


Fig. 12. Transformer for locomotive type Od delivered in 1920.

sisting of a heavy bolt which follows the windings down, as soon as they show any tendency to shrink, due to the pressure of a strong spiral spring. In the opposite direction the bolt is locked by a special nut with a ratchet so that the coils and bolts cannot be forced back when a short circuit occurs.

These transformers being intended for cooling by oil circulation the tanks are of plain sheet steel. The section is oval in plan and the flat sides are stayed by a large number of steel channel sections which are welded on. As the transformers are to be erected out of doors the covers are domed and all fittings on the cover are provided with raised flanges so that the rain water can run off easily without tending to get inside the tank. The terminals on the high tension side are condenser type bushings and have a flash-over pressure, dry, of 360 kV, the paper insulated interior is surrounded by a porcelain sleeve provided with a flange, and all space between this sleeve and the insulator is filled up with compound so that the bushing is well protected against damp.

At the commencement the transformers will work delta connected on the high tension side for 132 kV, but they are designed so that later on they can be star connected for 220 kV with earthed neutral point. These transformers are the first so far constructed in Europe for this working voltage. The transformers are being supplied with standard 132 kV insulator bushings as shown in figs. 5 and 6, and the intention is to exchange these for a larger type when the change-over to 220 kV is made.

The 10,000 kVA transformers for Hallsberg and Alingsas weigh 75 tons filled with oil, and the dimensions are 2,530 × 4,870 mm in width and length while the maximum height is 6,330 mm.

The transformers have been designed to be transported to site completely assembled and filled with oil, and in order to make the transport possible the Swedish State Railways obtained trucks which were specially built for the job.

The oil is cooled by means of a separately mounted oil cooler (see figs. 8 and 9), and for connection to this the transformer is provided with two 3″ valves. The oil coolers are of special type, the principle being similar to that of the coolers described below for the locomotive transformers. Cooling is effected by means of compressed air so that the cost of cooling water is saved. The general particulars are as follows:

Quantity of oil circulated 18,500 kgs per hour.
Losses dissipated 157 kW.
Quantity of cooling air 14 m^3 per second.
Power taken by the pump and motor driven fan 16 h.p.

Step-up Transformers for the Overhead Contact Line. The three-phase supply from the transformers described above is converted by means

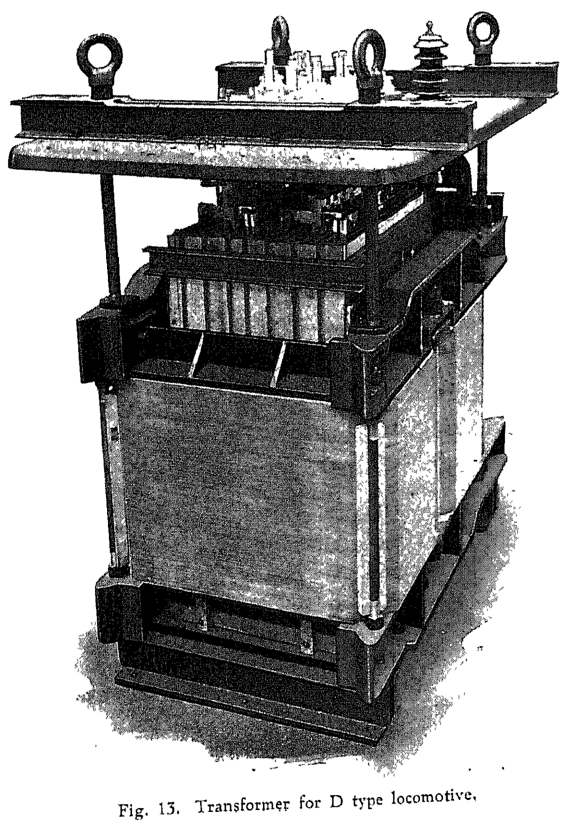


Fig. 13. Transformer for D type locomotive.

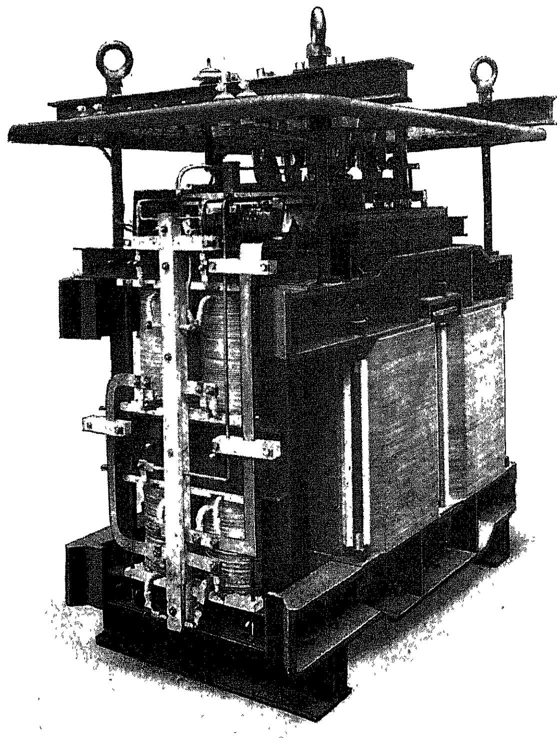


Fig. 14. Transformer for D type locomotive.

of rotary machinery in the railway sub-stations to single-phase at 3,000 volts and $16^2/_3$ periods. For stepping up this voltage to the necessary pressure for the contact line, 16,000 volts, twelve step-up transformers have been ordered, to be divided among the different stations, all exactly similar and built to the following data:

Type EO 77, 2,400 kVA, 3,000/16,000 volts, $16^2/_3$ periods.

These transformers, like the others, are of core type and fig. 10 shows an interior view of one of them. The transformers are constructed with two windings on each limb, the limbs being connected in parallel on the high tension side. The low tension coils are arranged of the spiral type as previously described, and the construction is accordingly very much the same. The transformers are arranged for cooling by means of natural draught, and as the losses are large in proportion to the output, on account of the low frequency, the oil tanks are constructed in a special manner. Fig. 11 is an exterior view of one of these transformers and it will be seen that the oil container consists of a main tank round the sides of which relatively deep cooling vanes are provided. To obtain sufficient radiating surface a number of oil cooling pockets are provided and furnished with similar cooling vanes. The pockets are removable so as to be accessible for cleaning.

All the stationary transformers are provided in the ordinary way with expansion vessels. The expansion vessel is connected by a pipe with a drying apparatus, mounted at a convenient height, in which calcium chloride may be placed for drying the air drawn in.

The following particulars apply to these transformers:

Total weight 22,500 kg.
Efficiency at Full Load 98.13 %.
No load losses 8.7 kW.
Short circuit voltage 5.9 %.

II. *Transformers for D-Type Locomotives.*

For the fifty locomotives of type D which are now under construction, locomotive transformers are being built by Asea with the following data: Type ECO 16 — continuous output, for the motors, 1,180 kVA, to which during the summer must be added 50 kVA for driving auxiliary machinery, and during the winter 260 kVA for train heating. The total output during the winter is accordingly 1,490 kVA. These transformers are designed for stepping down from the contact line voltage, the mean value of which is assumed to be 14,000 volts. On the secondary side they are wound for a maximum voltage of 840, and tappings for the motors are provided with the following voltages: 840, 672, 528, 384, 264 and 168. Besides the above, special terminals are arranged at 216 volts with extra tappings for + 10 %, this voltage being for driving the auxiliary machinery. The above main transformers are built in combination with regulating transformers and two current transformers, all of which are placed in the same tank.

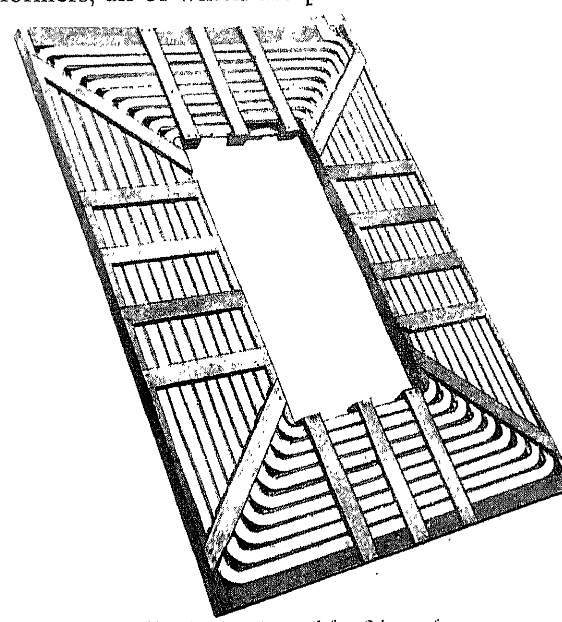


Fig. 15. Low-tension coil for Od transformers.

The Main Transformers. These transformers, chiefly for reasons of space, are of the shell type as this type allowed the overall height to be considerably reduced. For work of this nature, which naturally introduces particularly heavy mechanical strains and serious vibration, it is natural that the first requirement is that the transformers should be as strongly constructed as possible. For this reason all the older designs were carefully revised and a new type produced. The changes introduced can be gathered by comparing the illustration fig. 12, which shows the arrangement of the transformers for an older locomotive type Od, with figs. 13 and 14 which show the transformers for the type D locomotives.

As regards the special arrangement of the coils the original design can be gathered from fig. 15 which shows a low tension coil for the Od transformers. These coils are, as shown, wound from bare copper strip and insulated between turns by distance pieces of wood, the complete coil being held together by a wooden moulding. This construction, although it is still made use of by many other firms, introduces a number of weaknesses. That the strength of the wooden framework is not great will be clear if one imagines the coils themselves removed, when the moulding alone is quite unable to resist any great strains. Any particular pressure from without, tending to press the coils together, cannot be exercised, as the construction must be such that the different mouldings are not movable with respect to one another so that any tendency to press the coils together causes the framework to break. Lastly it may be mentioned that the wooden fillets crossing from side to side interfere to a great extent with the circulation of oil along the coils. The new arrangement adopted is shown in fig. 16. This figure shows a high tension coil, but the arrangement of the low tension coils is in general the same, which is attained by dividing the massive copper conductors previously used into a large number of parallel connected parts insulated from each other by a cotton covering. As the wooden mouldings cannot be considered sufficiently strong to hold the coils together these have been entirely done away with and the new coils are assembled instead with U-shaped collars of white presspahn which is stamped out to the form shown in the figure. The function of these collars is first to act as distance pieces between the neighbouring coils so that suitable oil channels are obtained for oil circulation on both sides of the coils. The projecting presspahn tongues are extended so that each turn in the coil when pressed together is separated at a number of different points along its length. With this construction, unlike the earlier one, the coils are held together by clamping devices acting from without which are so arranged that they act on the coils in all directions, and the stability of the windings depends in a considerable degree on the way these devices are arranged. The rigidity of the windings is increased considerably by the fact that the coils of this type are impregnated in a vacuum before assembly. Before this impregnation the coils are pressed together in all directions in a special former so that the exact dimensions required are obtained, and the pressure is maintained during the whole of the impregnation process. The result is particularly strong and rigid coils which do not shrink under the action of the clamping devices by more than a millimetre or two after assembly.

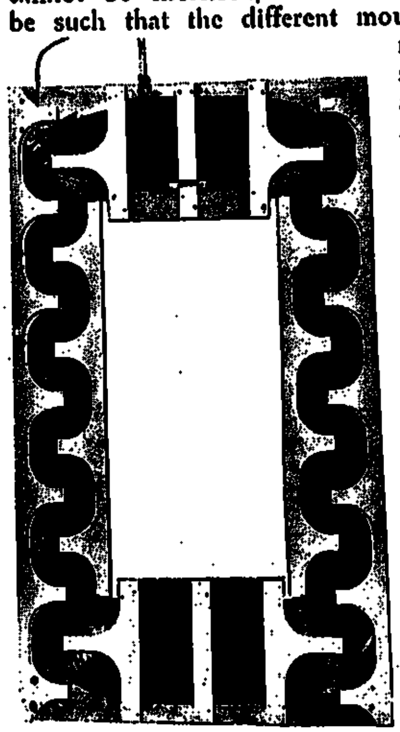


Fig. 16. High tension coil for D type locomotive transformers.

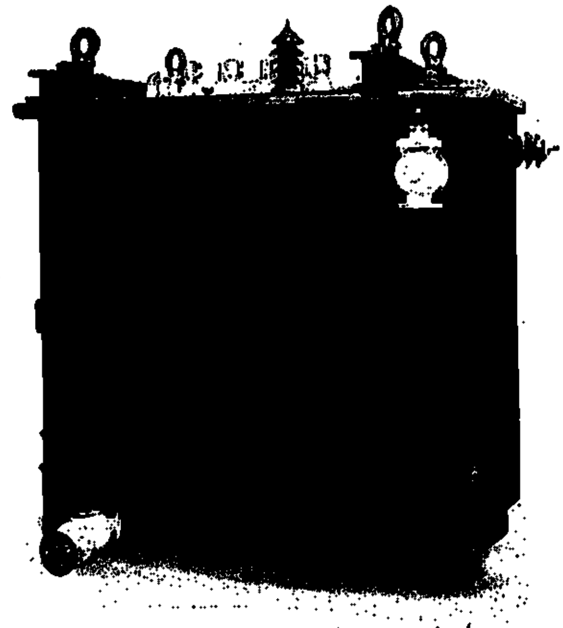


Fig. 17. Exterior of transformer for D type locomotive.

Regarding other details of the winding it may be said that in addition to the distance pieces referred to above the coils are also insulated from one another by strips of presspahn laid between. A number of high tension coils are placed together in this manner in a stack, and this stack of coils is insulated from the core and from the surrounding low tension coils by a system of presspahn collars of angle section. The system is constructed so that the different parts can slide past one another during pressing without becoming deformed in any way.

As regards the method of assembly for the windings on the core the new arrangement differs considerably from the old. In the latter the coils were fixed directly on the core and this meant that the windings could not be regarded as being held immovably in the vertical direction, since the core, which is constructed of 0.5 mm plate, cannot be regarded as solid and has a tendency to shrink to some degree during working. In the new transformers, for this reason, the supporting of the coils is entirely independent of the core and the coils are erected on a strong horizontal T section carried by bolts from the lower channel irons (see figs. 13 and 14). The section referred to can be pressed upwards by a nut, while the core plates by means of corner bolts, shown in the same figure, can be pressed together, and the windings and core plates are accordingly entirely independent of one another. In plan the windings are pressed together between pressing devices acting on the top and bottom ends of the coils, and the parts of the coils surrounded by the core are pressed together by a large number of vertical wooden wedges, which are visible in fig. 14.

The channel irons for the main transformers are castings in the new type and are considerably stronger than the old pattern which were made up from welded angle iron. The channel irons are extended for fixing the regulating transformers.

Special care has been given to the arrangement of the connections to the low tension windings as it has been found that these details are exceptionally sentitive to the vibrations which occur. From the coils accordingly connections are taken out in pressed bakelite tubes to busbars lying directly over the windings. These bars are exceedingly carefully stayed, each being provided with one or more separate supports. The connections between the busbars and the terminals have been made with a number of parallel connected stranded cables made from wire of particularly fine section. This arrangement has been shown to be capable of withstanding the continual heavy vibration which must be expected.

The Regulating Transformers. For running the locomotive sixteen voltage steps are required on the low tension side, and the simplest way of obtaining these would naturally be to provide the main transformer with a corresponding number of tappings on the low tension winding. It has, however, been found that an arrangement of the winding with such a large number of tappings would be greatly complicated, and in addition space is wanting on the cover of the transformer for a sufficient number of leading through insulators. For this reason regulation is carried out in accordance with a principle introduced by one of the Swedish railway officials by which the main transformer is provided with a considerably less number of tappings, and the voltage steps thus obtained are further divided by a separate transformer, which by means of the operating gear, is changed over to the different transformer tappings so that the whole range of voltage variation can be finely divided. The regulating transformers each consist of two units of which the larger cuts down the voltage per step to one half, and the smaller again divides the resulting voltage step by three.

Both transformers are, in the present case, built together into a single unit with a common core, and the unit can be seen to the left of fig. 14. The transformers are of ordinary core type with cylindrical windings. By making use of series and parallel connection of the different coils it is possible to arrange not only for the four coils of each transformer to have the same number of turns, but also that all the eight coils can be wound with copper of the same dimensions. The winding is done with bare copper strip on edge and insulated by presspahn rings between turns. As the frequency is low no transposing of the windings is necessary, but as stated they can be made with a heavy section so that the arrangement is particularly simple and strong. The coils are vacuum impregnated in the usual manner. The regulating transformers are connected to four separate leading through insulators in the transformer cover.

The transformers are placed in a common oil tank of which fig. 17 shows the external appearance. The transformer core must of course be very carefully stayed to the tank so that all movement is prevented, and special arrangements have been made to accomplish this. In order to prevent movements in the horizontal direction the transformer tank is provided at the bottom with four removable covers, of which

one can be seen on the extreme right. Inside strong angle irons are placed fixed to the tank, and provided with a number of locating screws which are accessible after the inspection cover has been removed. These screws press against the ends of the lower yoke channel irons of the main transformer and act in four directions. At the same time, as a very effective fixing of the transformer core is obtained by this method, the placing and adjusting of the transformer in its tank is very simple and can be carried out without very careful location. For fixing the core in the vertical direction two girder sections are provided above the cover which can press downwards through vertical lifting bolts which pass through the cover. The pressure from these is transmitted through the girders to four lifting bolts, visible in figs. 13 and 14 carrying the cover and in this way the transformer is pressed tightly against the bottom of the tank and all danger of the core jumping in the tank is obviated while the locomotive is running.

It is of equal importance that the complete transformer should be firmly fixed to the locomotive frame, and this fixing is carried out in a similar manner. The vertical lifting bolts just referred to, which are outside the tank are fixed direct in the foundation of the transformer and prevented from moving in the vertical direction. The base consists of a cast and machined steel plate which is provided, at the corners of the transformer tank, with cast lugs with bolts pressing tightly against the transformer horizontally. For taking up this pressure the transformer tank is strengthened at the corners with iron plate welded on as shown in fig. 17.

Coolers. The transformer oil is cooled in an oil cooler, mounted separately, by means of compressed air, fig. 18. The arrangement with separate cooler is used so that the transformer tank can be made heavier and stronger than would be the case if it had to provide at the same time sufficient cooling surface. The transformer tank is provided with two oil valves for the entering and leaving oil and pipes carry the oil via a motor driven pump to the cooler. The fan for supplying the necessary quantity of air is mounted on the same shaft as the pump so that only one driving motor is required. The cooler is erected on a cast steel bedplate, into which the air is forced and thence passes in the vertical direction upwards through the cooler. The cooler itself consists of a large number of similar parallel connected cooling elements. These elements are constructed in the form of flattened tubes placed on edge and mounted at a small distance from each other and having distance pieces of sheet iron, the air supplied being forced between them. At the ends these elements are welded to one another and the unit so obtained is welded into a strong frame having cast iron end covers provided with feet for supports. The oil is led into and taken from these end covers. The oil then passes through the cooler in the horizontal direction inside the elements while the air passes outside in the vertical direction.

The coolers are subjected to a vibration test, before delivery, filled with oil and mounted on their bedplates.

Data.

Weight of complete transformer, excluding oil 7,900 kg.

Weight of oil 2,100 kg.

Efficiency at 1,230 kVA $\cos\varphi = 1.0$, 97.5 %.

Efficiency at 615 kVA $\cos\varphi = 1.0$, 97.95 %.

Total losses with winter load 43.5 kW.

Weight of cooler including bedplate and oil 985 kg.

Quantity of oil circulated 200 dm³/min.

Quantity of air circulated 200 m³/min.

Power required for fan and oil pump 14 h.p.

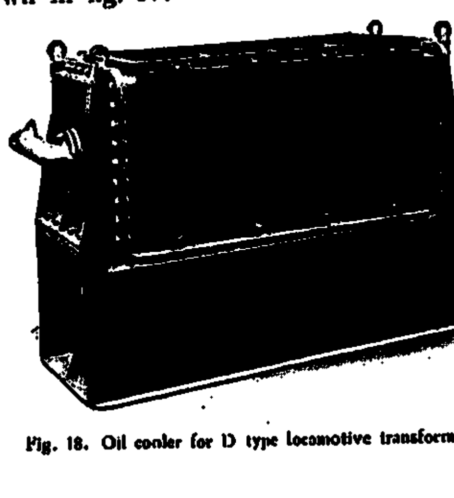


Fig. 18. Oil cooler for D type locomotive transformers.

ELECTRIC ROTARY SNOW PLOUGHS FOR THE RIKSGRANS RAILWAY, SWEDEN.

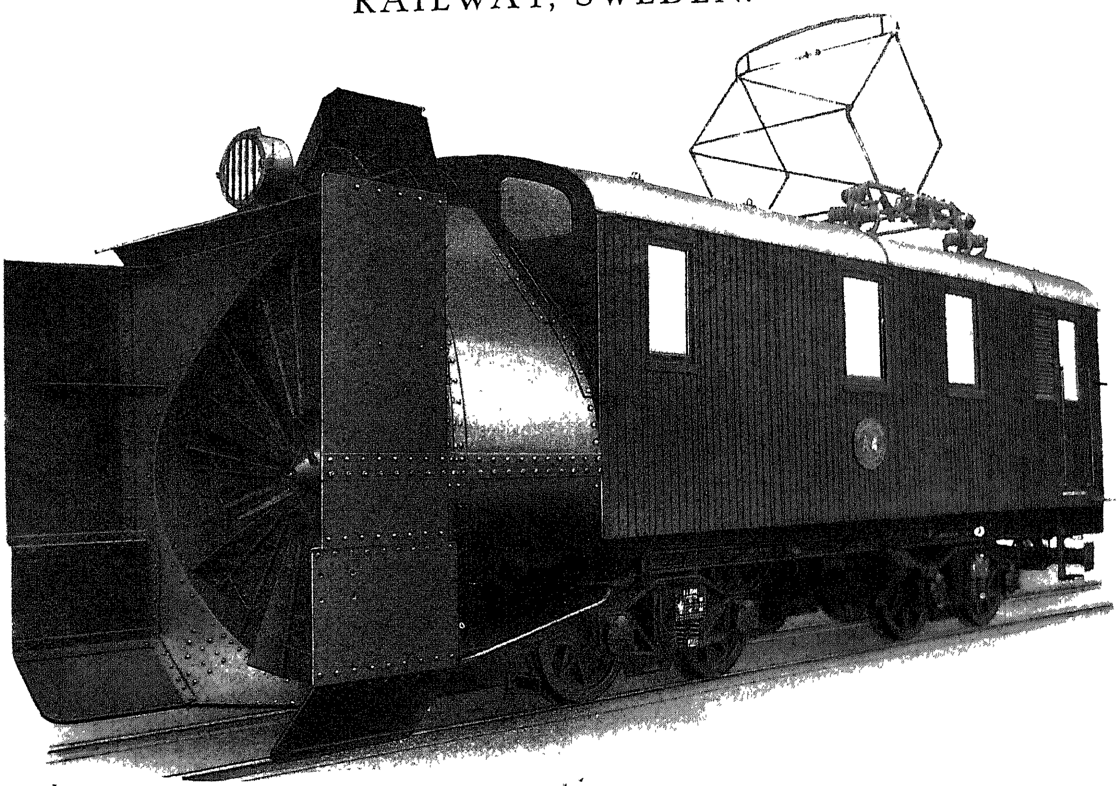


Fig. 1. One of the new electric rotary snow ploughs for the Riksgrans Railway, Sweden.

The section of the Swedish State Railway between Lulea and Riksgransen, known as the Riksgrans Railway, lies above the Arctic Circle, and it follows that special measures have to be taken to deal with the semi-Arctic climate which causes particularly severe winter conditions in the area served by the line.

One of the greatest difficulties to be contended with is that of keeping the line clear of snow during the winter. Since the line has a length of approximately 450 km largely through uninhabited districts, and as during a heavy snow storm drifts several metres in depth can cover the line in a few hours, it will be obvious that the work of keeping the track clear, if carried out by hand alone, would be in the highest degree arduous and would provide continuous work for hundreds of men, even if the necessary staff could be housed in such a region.

It follows that suitable mechanical arrangements have had to be obtained, and these are being added to and improved from time to time, the latest development in this direction being represented by the two rotary snow ploughs which were delivered last year to the Riksgrans Railway by Asea. These are probably the only snow ploughs in the world designed for electric drive.

The principle on which these ploughs work is that of using a large rotating plough wheel which throws the snow out to the side of the track, while the whole machine at the same time moves forward along the line. Fig. 3 shows one of the machines at work, although handling only a small amount of snow.

The plough wheel, together with the motor for turning it and the other machinery necessary, is mounted on a railway waggon which is provided with a driving cab and machinery compartment. The waggon is carried on two goods truck bogies, and the axle pressure is 16.5 tons on the forward and 10.5 tons on the rear bogie.

The snow plough is not provided with locomotive power, but is pushed from behind by an electric locomotive which can be controlled from the driving cab of the snow plough.

The motor for driving the plough wheel shaft has a one-hour rating of 565 h.p. and can be momentarily overloaded with nearly double the torque corresponding to this output. The driving motor is designed as a series wound

single-phase motor of the same type and appearance as those used for locomotives of type Od. These motors have been already described in the Asea Journal, July 1924.

Fig. 2 shows the arrangement of the snow plough, together with the location of the various machinery.

The framing is very strongly designed to meet the unevenly divided loads which occur in use. The body of the waggon is built of wood on angle-iron framework, and is lined inside with wood panelling. The roof is divided into a fixed portion in the middle and two removable parts. The fixed part of the roof carries the current collector and leading through insulator. The roof is covered in the usual manner with impregnated roofing material.

At the forward end of the plough is fixed the housing of the plough wheel. The sides of this are made from steel plate 15 mm thick, and the whole is made fast to the under-frame with heavy inclined stays. The plates of this housing form the greater part of the front wall of the driving cab, but inside the cab they are lined with wood. At the top part of the housing the sides are made to approach in sector form. In this upper part there are no covering plates, so that an opening is provided through which the snow can be thrown out. A shutter can be adjusted from inside the driving cab so that the snow can be thrown out to either side and at any angle between the two limiting positions. The operation of this shutter is by means of a screw which can be turned by a handwheel. The cover of the ploughwheel is continued forwards, and two side guards or screens are extended out, which in travelling, cut out the snow and determine the load which the plough is to remove. The lower part of the extended front of this cover is horizontal, and is provided with a V-shaped cutter with a blade of hardened steel. The cover is divided horizontally, and the plates forming it are so arranged that the upper half can be lifted off, so that the machinery and plough wheel, together with shaft, can be lifted out of the plough after removing the forward part of the roof. The housing is provided with a snow screen on top, on which the headlight is placed. Heavy steel plate is used throughout in the construction of the housing.

The plough wheel is made with 10 cells of cucullated form, and the bases of these rest on the baseplate of the wheel. The outer edges are sharp, and are made fast to a cast steel cell base in such a way that the outer edges are in a higher plane than the respective bases. The cells are open in front throughout their length. This opening is partly covered by two knives of hard steel which can be turned round radial axles, one being placed at each edge of the opening. The knives are connected together in pairs in such a manner that they take up a suitable position according to the direction of rotation of the wheel. When the knives on one

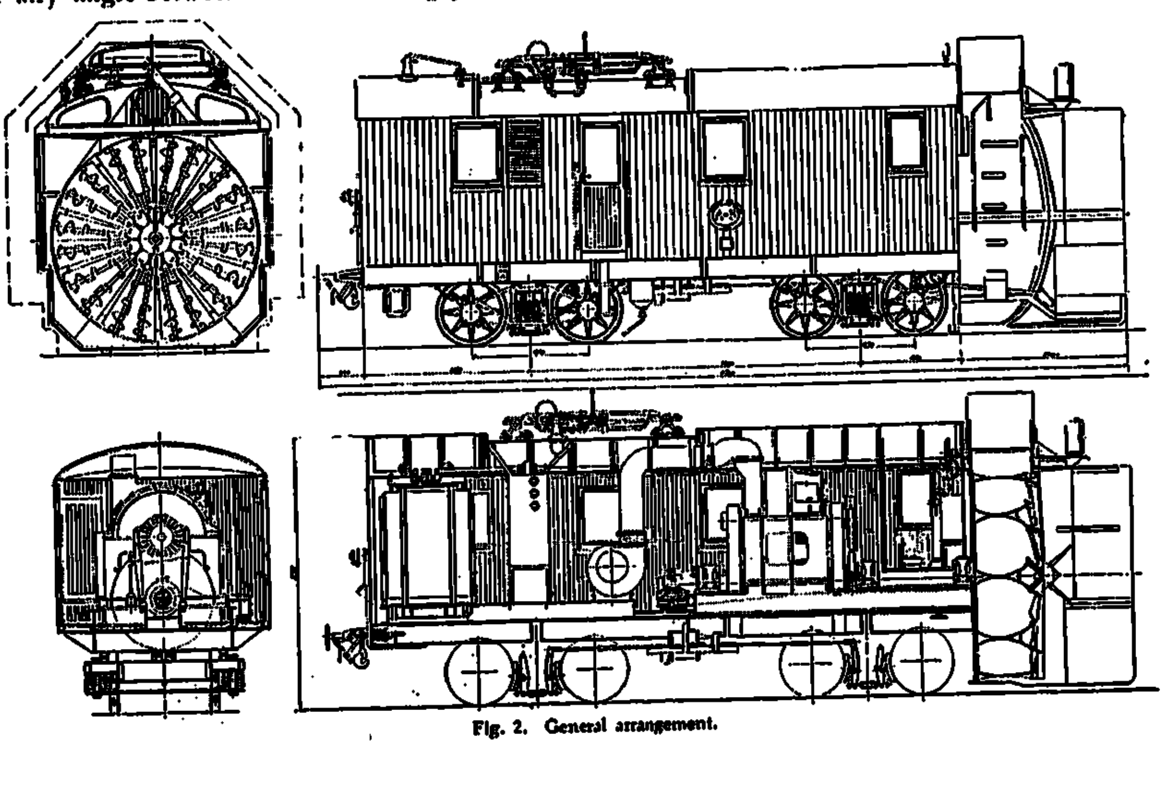


Fig. 2. General arrangement.

side of the respective cell openings (*i.e.* the knives which lie in the direction of rotation) come into action, there is accordingly a reaction pressure, which due to the connecting links forces the knives on the opposite sides of the openings to be withdrawn. The size of the openings is limited by stops on the operating rod. The plough wheel is held together by a strong cast steel boss which is keyed on to the shaft. At the forward end the shaft is completed by a casting of conical shape, keyed on, to which two strong "horns" are fixed. These are intended to break up hard frozen pieces of snow, so that they will enter the wheel easier. The diameter of the plough wheel is 3,000 mm. The normal speed of rotation is 125 r.p.m. At 170 r.p.m. the motor current is automatically broken by a centrifugal switch which is placed on the shaft inside the machinery compartment.

The plough wheel shaft, which has a diameter of 220 mm, rests in three sleeve bearings which are carried on the machine bedplate. The axial thrust is taken up by an SKF thrust bearing with 66 mm balls, and designed for a maximum load of 20 tons.

The motor, which is placed longitudinally, is provided with a cast steel stator frame which is bolted to the bedplate. It drives the ploughwheel shaft through a helical single reduction gear. The gear pinion is combined with a brake drum, and against this two brake blocks can be pressed, these being operated by air pressure from the driving cab. In this way both the rotor and the plough wheel can be braked at the same time.

Most of the remaining electrical equipment is erected in the machinery compartment. This includes the compressed air operated current collector, oil immersed circuit breaker for the high tension supply, the transformer, switchgear frame, and a motor driven ventilator for cooling the transformer and plough wheel motor. All these parts are of the standard design as fitted to electric locomotives, and generally similar to the equipment on the Swedish State locomotives, type Od. (See Asea Journal, July 1924).

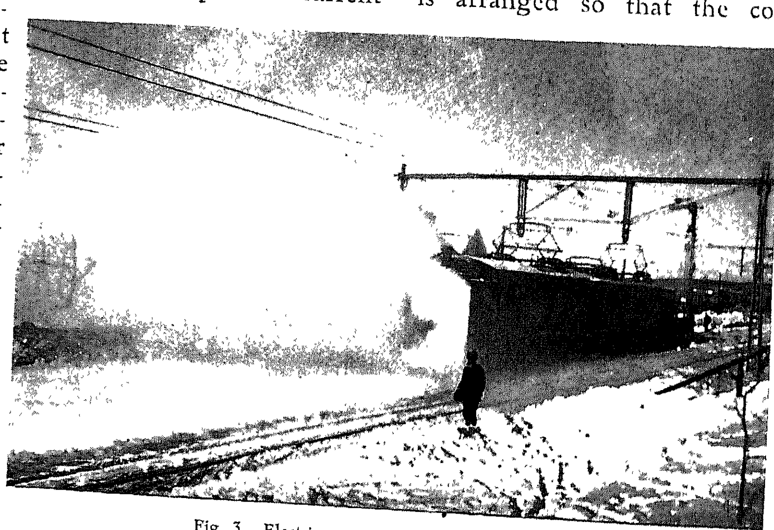


Fig. 3. Electric rotary snow plough in action.

The current is taken from the contact wire by a current collector of pantograph type, and is led through a high tension leading through insulator to the oil immersed circuit breaker, which is enclosed in a special high tension compartment at the back of the machine. The door to this compartment cannot be opened until a short circuiting arrangement has been operated, which earths the high tension connections. From the circuit breaker the current is taken to the transformer, where the pressure is reduced to a suitable value for the motor. The motor voltage is regulated in the same way as it is on the Asea single-phase locomotives, by connecting different secondary terminals on the transformer by relays to a reactance coil in three divisions, by which means three times as many voltage steps are obtainable as there are transformer tappings. The total number of steps provided is ten, in addition to the main running position. Reversal of the direction of rotation of the ploughwheel is obtained by an electromagnetically operated drum contactor which reverses the direction of the current in the motor field. This can only be operated when no current is passing through the motor, by means of a lever on the plough wheel controller. The motor relays are closed by current from the main drum of the controller. In addition to this apparatus overload relays are provided, also lighting switches ventilator, and no-volt relays etc., also the necessary heating and lighting arrangements, the principle adopted being the same as for the Asea single-phase locomotives. All the apparatus is mounted on a common framework.

The ventilation of the motor and transformer is arranged so that the cooling air is drawn through a system of tubes arranged vertically in the transformer tank, into the ventilator, and afterwards forced through the cooling ducts of the motor.

In the driving cab the floor level is raised, so that the driver is able to obtain a lookout through the windows, which are placed rather high. In the cab, in addition to the

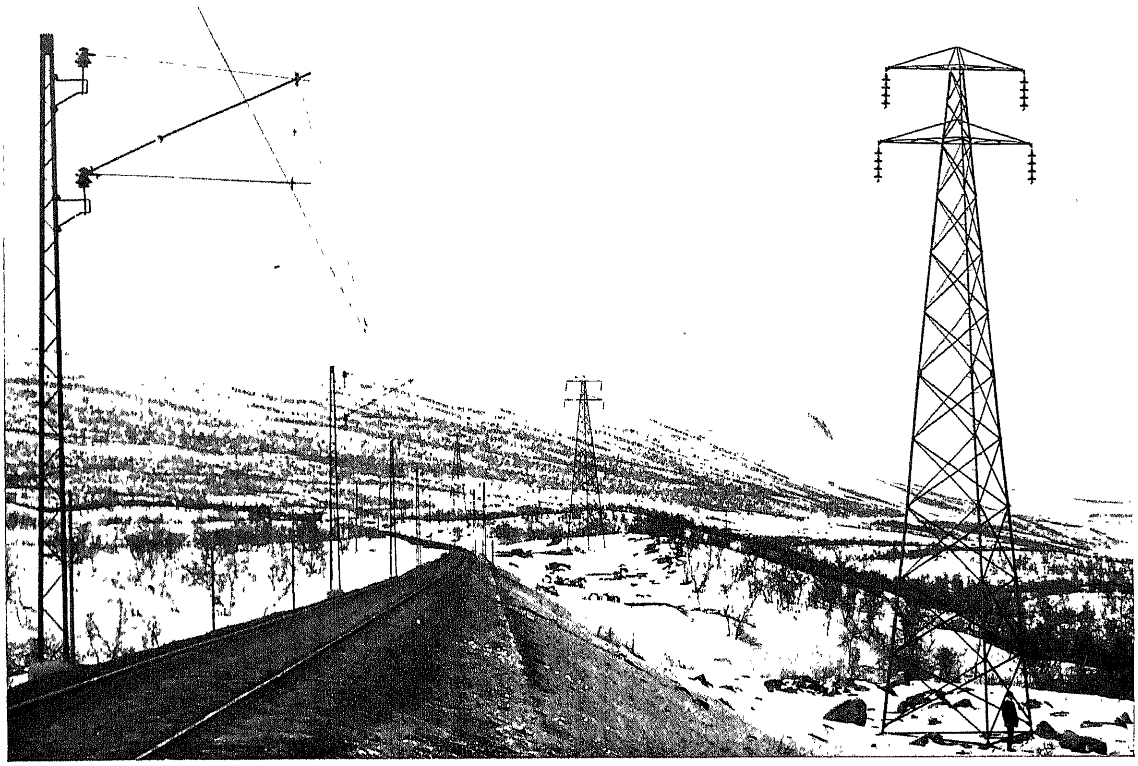


Fig. 4. Transmission line and contact wire for the Riksgrans Railway.

lever for operating the shutter in the plough wheel housing, there is placed a handle controlling the rail scraper, a hand-brake, and operating handles for the air-brake, the plough wheel brake, sand apparatus and whistle; also a tachometer for the plough wheel and controller for working the plough wheel motor contactors, as well as the controller for operating the banking locomotive.

The driving cab is provided with heating apparatus. Instruments include a voltmeter for the overhead line voltage, an ammeter for the plough wheel motor, and a switchboard for the lighting and heating installation.

On the buffer board of the snow plough are fitted two multiple plugs for connecting to the banking locomotive, so that this locomotive can be driven from the driving cab. The snowplough is provided with the standard air-brake adopted by the Swedish State Railways. Compressed air is obtained from the compressor of the banking locomotive, and the snowplough is provided with train pipe, valves and brake pipe connections, so that the air-brake on the locomotive can also be controlled from the driving cab of the plough.

These snow ploughs have been in use during the whole of last winter, and have operated in a perfectly satisfactory manner.

The large rotating masses have been found well balanced, and the whole of the machinery has run in a very quiet and vibrationless manner.

The electrical and mechanical equipment has all been supplied from the Asea shops in Vesteras.

ASEA-JOURNAL

ALLMÄNNA SVENSKA
ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5. CHANCERY LANE—LONDON

VOL. II
1925

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesterås, Sweden.

NOVEMBER
No. 11

Interior of the Norwegian State Power Station, Glomfjord, equipped with three Asea generators having a total kVA capacity of 68,000.

ASEA SELF-STARTING SYNCHRONOUS MOTORS.

In a foregoing number of the Asea Journal (1925 No. 2) an article will be found which describes the general construction of Asea synchronous motors, and refers to the economic significance of synchronous motors as a means of improving power-factor. An important contributary cause of the greatly increased use of these machines at the present time is the vast improvement which has been made in the methods of starting, and in the simplification of the methods commonly in use. By way of completing the article referred to we shall now describe the manner and routine of starting synchronous motors in accordance with the methods commonly used by Asea.

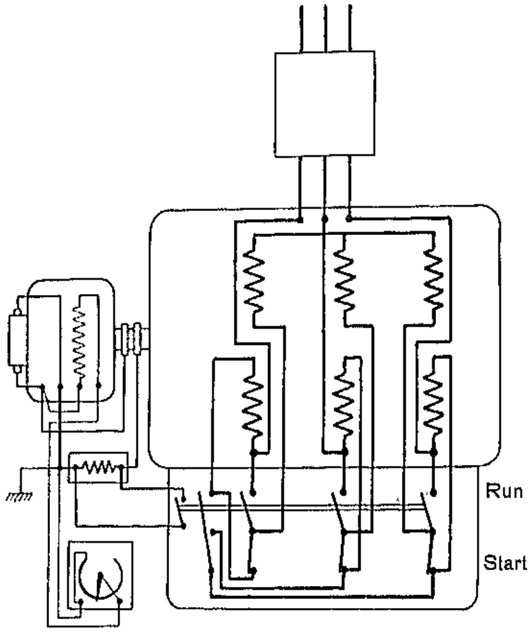


Fig. 1. Connection diagram for self-starting synchronous motor with changeover switch for series-parallel connection mounted on the motor.

A self-starting synchronous motor can be started, as the name suggests, without the help of another motor, and is also self-synchronising. The motor starts asynchronously and runs as an induction motor nearly up to the synchronous speed. The asynchronous torque, with synchronous motors of Asea's normal design, is produced by interaction between the rotating stator field and the eddy currents caused by this field in the massive rotor iron. The rotor field winding is of no special importance during starting and at this period may be either open-circuited or short-circuited. The greatest torque is obtained with an open-circuited field winding; with a short-circuited field winding the torque is somewhat impaired. Starting with an open-circuited field winding however means that both winding and sliprings must be able to withstand the pressure, often comparatively high, which the stator field induces in the field winding. On account of this fact — and for another reason also which will be clear from the following — a fixed resistance is connected between the sliprings in series with the exciter. By suitably dimensioning this resistance the voltage between the sliprings during starting can be kept sufficiently low without the current in the field winding becoming so great as to weaken the torque to any troublesome degree. This resistance is not of course a 'starting resistance' in the usual sense of the term.

The motor, commonly, has a direct connected, shunt wound, exciter. When full asynchronous speed is reached, the exciter voltage has built up, and the field of the synchronous motor is thus weakly magnetised, since the field circuit is closed through the fixed resistance. The motor therefore immediately drops into synchronism

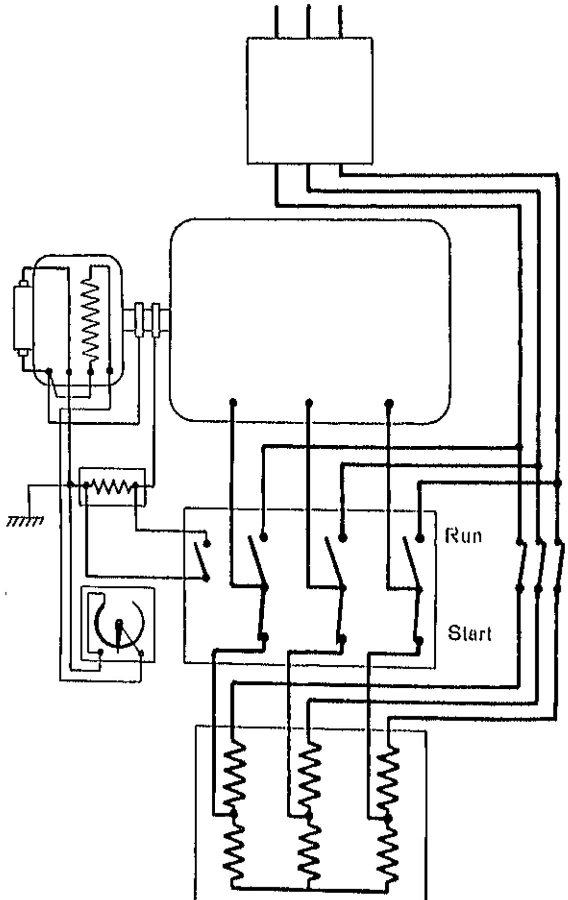


Fig. 2. Connection diagram for self-starting synchronous motor with auto-starter and changeover switch for changing phase by phase.

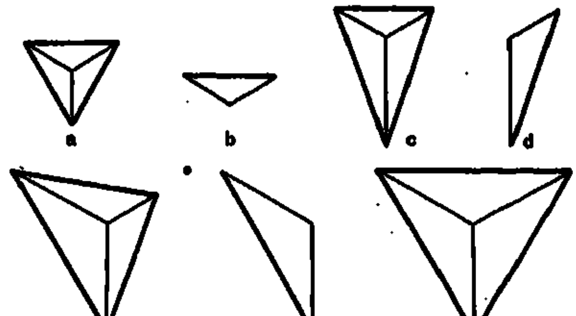


Fig. 3. Diagram of pressures on the statorwindings when changing over phase by phase.

with correct polarity, under the assumption naturally that the load conditions are such as to make synchronism possible. (Even if the field is not magnetised in this way with continuous current there is still a synchronising torque, due to the salient pole formation, which can draw the rotor into synchronism). If the motor is excited from a separate source, the field is first excited when the motor has reached full speed.

In order that the starting current may not be too great it is usual to start with reduced voltage, or to provide the motor with a stator winding which can be reconnected for starting in such a way that the impedance is considerably greater than it is for normal running. In the former case an auto-transformer is used, while with a reconnectable stator winding series-parallel connection is the most common, although Y/D connection may also be employed. When full speed has been reached, the motor is quickly switched over to full voltage, *i.e.* to the normal running position, and at the same time the fixed resistance in the field ciruit is shunted. The field current can thereafter be regulated in the usual manner.

The starting method which has most often been used is the series-parallel method. The stator winding of the motor is then furnished with two parallel circuits per phase; the leads necessary for reconnecting the winding are taken to a change-over switch, which in small units is placed on the motor itself, and with larger units is made for separate mounting. The diagram of connections is shown in fig. 1. During start, which is carried out by closing the main circuit-breaker with the change-over switch in the starting position, the two circuits are connected in series with each other, so that the impedance is four times as great as it is with parallel connection. The starting current (the line current) is commonly, with a motor of normal design, about equal to the full load current; if the reactance can be made particularly large, without disadvantage to the other characteristics of the machine, — e.g. by using a large number of conductors in the stator winding — and the motor is started at no load or with inconsiderable load, the starting current can be kept still lower. When the motor reaches synchronous speed, the stator winding is reconnected by rapidly throwing the change-over switch into the running position.

The series parallel connection method is used for low tension motors up to about 300 kVA. It can also be employed for larger units up to about 1,000 kVA and for higher voltages, 3,300 volts and higher, provided that the large number of conductors made necessary by the parallel connection does not give rise to difficulty as regards insulating between the conductors. For outputs above 300 kVA the change-over switch is furnished with a resistance to protection at changing over from series to parallel connection. Series-parallel connection may even in certain cases be used for larger units than those of 1,000 kVA as referred to above; in order to reduce the current rush when changing over, phase by phase changing over can be used (a description of this method of reconnection is given below).

Somewhat similar to the above in operation is Y/D connection, which is often used for small induction motors, and can also be employed for self-starting synchronous motors. With Y/D connection the starting current — other things being equal — is 33 % greater than with series-parallel connection; the starting torque is also increased in the same proportion. It is important that the change over from Y- to D- connection is done in correct phase order, so that the least possible current rush is caused.

Starting with an auto-starter, a method which can be used for all voltages and outputs, introduces the advantage that the starting voltage can be reduced to the most suitable value for any particular case, by a careful choice of the ratio of transformation of the auto-transformer used. In this way it is often possible to keep the starting current lower than it would be with series-parallel connection. Auto-starters are preferably used for large motors; for smaller motors they are used only when a reconnectable winding is unsuitable, e.g. when the working voltage is high. For starting with an auto-starter the motor is furnished perfectly standard, and without extra terminals. A change-over switch is placed between the motor and the auto-starter for throwing the motor direct on the supply when full speed has been reached. For outputs above 300 kVA the change-over switch is provided with a protecting resistance,

Fig. 4. Oscillogram of starting current (I) and starting torque (M) for self-starting synchronous motor.

For units larger than 1,000 kVA the change-over switch is commonly arranged so that the reconnection to full voltage takes place one phase at a time, and the rush of current is diminished. For diagram of connections see fig. 2. It will be seen that, while for small units all three phases of the change-over switch are operated at the same time, here the threephases are separately connected to the full voltage. The change-over is made so that the motor is at no instant altogether disconnected from the line and during reconnection the machine runs alternately as a single phase and as a three-phase motor with successively increased voltage, see fig. 3. Before reconnection begins the motor runs three-phase with reduced voltage (fig. 3 a). When phase 1 is broken, the motor runs single-phase with reduced voltage on phase 2—3 (fig. 3 b), and when phase 1 is connected over to full voltage, the motor runs three-phase with unsymmetrically distributed pressure (fig. 3 c). After breaking phase 2 the motor runs single phase again (fig. 3 d) and after connecting phase 2 to the full voltage, three-phase, still with unsymmetrical pressure (fig. 3 e). When phase 3 is broken the motor runs once more single-phase with full voltage on phase 1—2 (fig. 3 f), and lastly when phase 3 has also been connected to full pressure, the reconnection is completed and the motor has normal voltage on all three phases (fig. 3 g). During reconnection the field current of the motor should be kept at a value equal to the no-load magnetisation for the intermediate voltage between the starting and running voltages.

When the line pressure is high it is sometimes found suitable to use a transformer and construct the motor for low tension. The transformer can then be furnished with suitable starting-tappings and an auto-starter is not required. In other respects the arrangement is the same as for starting with an auto-starter.

Fig. 4 shows the oscillogram of the current in one phase of the stator of a self starting synchronous motor. At first sight the variation in the starting current appears to be very curious with its corresponding maxima and minima sometimes symmetrically and sometimes unsymmetrically arranged. This is explained by the fact that the stator bars of the phase considered continually take up different positions with respect to the salient poles of the rotor. The manner in which the stator current varies with the position of the phase in relation to the poles can be determined by taking successive readings of the stator current at constant voltage with the rotor locked in a number of different positions. The current is greatest when the conductors composing the phase lie midway between the poles, and least, when they lie in the middle of the pole surfaces. Between these values the current varies approximately as a sine curve about a mean value. Thus when there is a given angle α between the centre of the phase and the middle of the pole pitch the current is:

$$I = I_{mean}(1 + \varkappa \cos p\alpha)$$

where $\varkappa$ is the relation between the amplitude of the variation of the current about the mean value and this mean value; p is the number of poles of the machine. The instantaneous value of the current is

$$I_{inst.} = \sqrt{2}\, I_{mean} \cdot (1 + \varkappa \cos p\alpha) \cos 2\pi \nu_1 t$$

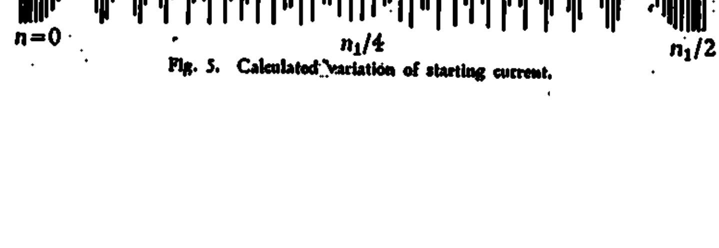


Fig. 5. Calculated variation of starting current.

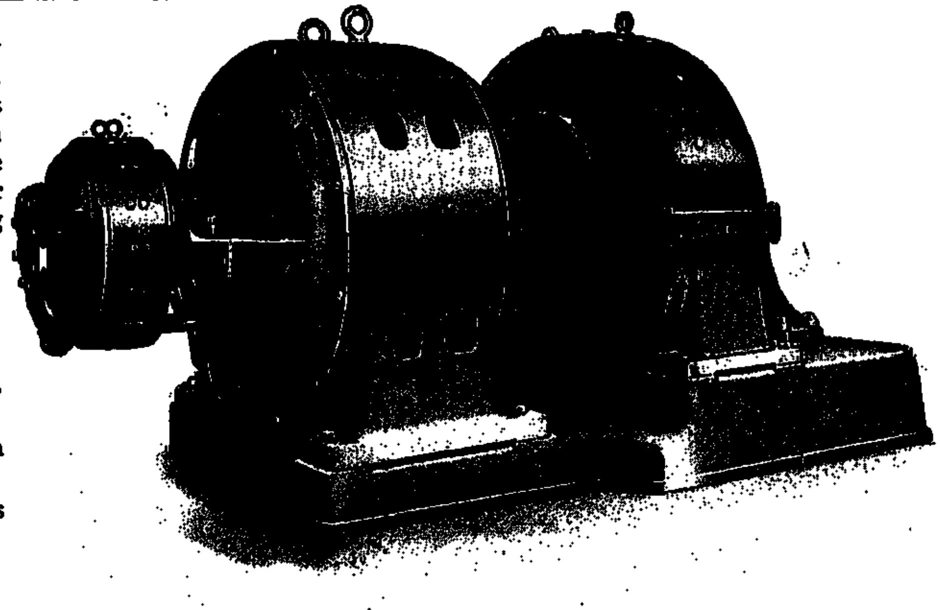


Fig. 6. Motor generator, 500 kW, 500 r.p.m., consisting of self-starting synchronous motor, DC generator and exciter.

If the angular velocity of the rotor at a given instant during starting is ω, the moment of inertia of the rotor J, and the torque acting on the rotor M, we have the following equation

$$M = J\frac{d\omega}{dt}$$

from which

$$\omega = \frac{M}{J}t \text{ if } t = 0 \text{ for } \omega = 0.$$

Putting $\omega = \frac{d\alpha}{dt}$ we obtain

$$d\alpha = \frac{M}{J}t\,dt$$ and from this

$$\alpha = \frac{M}{J}\cdot\frac{t^2}{2}$$

if $\alpha = 0$ for $t = 0$, *i.e.* the conductors in the stator phase are assumed to lie midway between the pole-shoes at standstill. With this value of α used in the expression for current we obtain

$$I_{inst.} = \sqrt{2}\, I_{mean}\left(1 + \varkappa \cos p\frac{M}{J}\cdot\frac{t^2}{2}\right)\cos 2\pi\nu_1 t$$

For $\nu_1 = 50$ cycles, amplitude values of the current are obtained by putting t, in the above expression, $= 0$, 0.01, 0.02, etc. In this way, with given values for $\varkappa$, p, M and J, the variation in the current is calculated up to half the synchronous speed (above this speed the torque is not constant). The result is indicated in fig. 5. For the sake of simplicity parallel vertical lines have been drawn in the figure instead of a continuous sine curve; in the actual oscillogram one can only distinguish straight lines on account of the abbreviated time scale.

The calculated curve shows the same characteristic appearance as the corresponding part of the oscillogram. The appearance of the curve, of course, depends on the position which the stator phase takes up from the start in relation to the poles, but the character is always the same. In the neighbourhood of $n = 0$, the amplitude curve is practically of sine form. Certain speeds are particularly marked, e.g. one fourth and one half of synchronous speed. These and certain other speeds can always be recognised in an oscillogram of starting current. By counting the maxima in the oscillogram we can, knowing the frequency of the current, determine the time in which a certain speed is reached, and from this, if the moment of inertia of the rotor is known, the torque developed can be calculated.

In calculating the variation of the current we have neglected the transient phenomena which actually occur when the switch is closed, but which only cause slight peaks and lack practical importance. Besides this we have assumed that the current, as it proceeds, varies about a constant mean value. Actually the current falls as the speed increases, so that the effective mean value of the current for the whole starting period, is less than the current at the commencement of the start. When the starting current of the motor is given, this always refers to the mean value of the currents in all three phases, which can be read on ammeters connected in them, an instant or so after closing the switch. At the actual instant of closing the hands of the ammeters commonly oscillate so violently that it is difficult to take any definite reading.

When the stator winding is switched over to full voltage, there is a sudden kick in the current but this also is not of practical importance, after which the current takes up a value corresponding to the magnetisation of the motor.

Fig. 4 shows a curve of torque during starting. (The oscillogram again gives a current proportional at every instant to the torque, the relatively slow rise of the curve from zero up to the constant value, depending on the time constant of the oscillograph circuit. The serrations in the curve are due to harmonics in the current and are not derived from variations in the torque). Up to half synchronous speed the torque is practically constant, = the starting

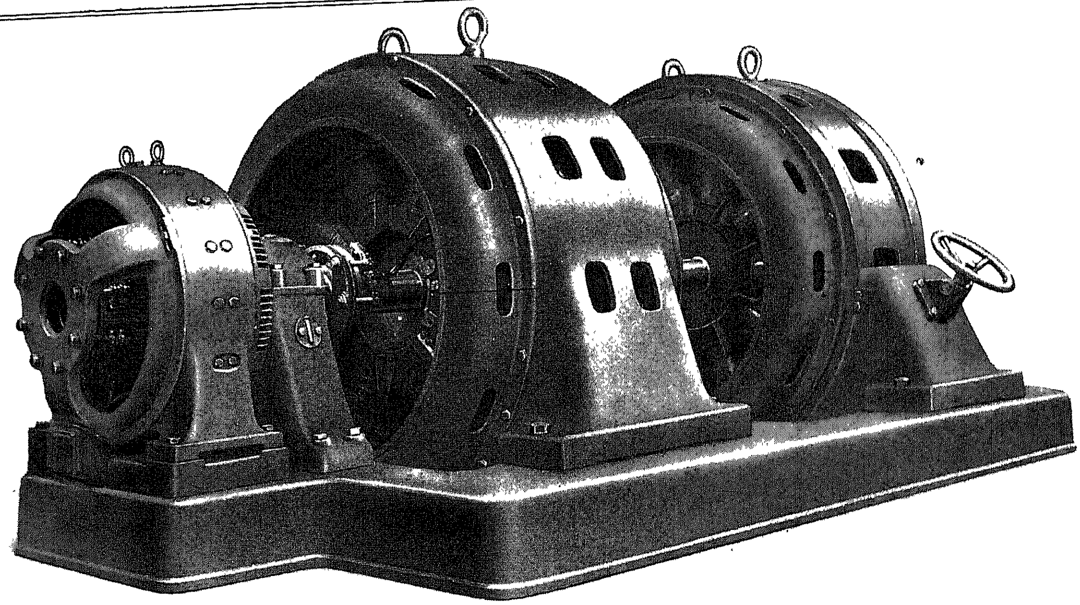


Fig. 7. Frequency changer, 500 kVA, 600 r.p.m., 40/50 cycles, consisting of self-starting synchronous motor, synchronous generator and exciter.

torque. At half synchronous speed the torque falls off, partly on account of the single phase action of the field winding, and partly because the rotor, having salient poles, gives rise to a certain single-phase action caused by the eddy currents in the rotor iron. After this the torque slowly increases up to the neighbourhood of synchronism, after which it falls off and becomes zero at full synchronous speed. When the slip is small enough to allow synchronism to take place, the rotor pulls into step, possibly after a few small oscillations.

The starting factor, *i.e.* the relation between the starting torque in % of the normal torque, and the starting current in % of the normal current is approximately 0.15 to 0.2. By starting torque we here understand useful torque over the starting friction torque of the motor; the normal torque is referred to full kVA and over excitation to $\cos \varphi = 0.9$. With series-parallel connection the starting current, as we have said, is approximately equal to the full load current, and the starting torque is accordingly about 15 or 20 % of the full load torque. If an auto-starter is used the starting current can commonly be reduced to a considerably lower value than the full load value, if the motor is to start at no-load; on the other hand it is also possible to increase the starting torque when desired, provided a corresponding increase in the starting current can be allowed. The starting factor is naturally the same whether an autostarter or reconnectable stator winding is used.

The low value of the starting torque in relation to the starting current is due to the fact that the power factor is low, commonly about 0.3. If the supply system to which the motor is connected is at all large however, the sudden throwing on of a load corresponding approximately to the kVA capacity of the motor at low power factor will not cause any inconvenience.

As regards the field of use of the ordinary synchronous motor, where arrangements for self starting may be used with advantage, we can first refer to synchronous motors for power factor correction *only* and to motor generators and frequency changers, driven by motors of this type. For such service the starting torque of the self starting synchronous motor is fully sufficient. The starting characteristics of the motor are best utilised if the starting conditions are such that the greatest starting torque is required at the commencement of the start, since the motor developes the greater torque in the first part of the starting period. If increased torque at increased speed is desired the self starting synchronous motor is less suitable. In such cases, and in general when high starting torques are required, special constructions must be taken in hand.

In the last few years the question of improvement of power factor on AC systems has become very acute, and synchronous motors are being largely used on this account. Asea has constructed a very large number of synchronous motors for various purposes and those turned out during the last ten years or so have mostly been arranged for self starting by one or another of the methods which we have described above.

THE MAGNETISING CURRENT OF TRANSFORMERS.

The deformation caused, by the variable permeability of the iron, in the curve of magnetising current of a transformer, is of great importance in a three-phase network due to the fact that, with voltages of sine wave form, the sum of the currents in the three phases is not zero, and an unbalanced current component arises. If the transformer is Y-connected this current cannot exist if there is no neutral lead but, in that case, the sum of the phase voltages differs from zero instead, so that the neutral point has a certain voltage to earth. If the current — or voltage — is resolved into fundamental and harmonics, it is easily seen that in a symmetrical three-phase system, it is the harmonics whose order is divisible by three which give rise to neutral point currents or voltages respectivly, since they are in phase with each other in all three phases. It also follows from this that with Δ-connection these harmonics disappear in the line voltages and line currents respectivly. Remaining harmonics, on the other hand, generate symmetrical three-phase systems in the same way as the fundamental. For harmonics of the order $3m+1$, where m is an even number, (7, 13 etc.) the direction of rotation is the same as that of the fundamental, while for harmonics of the order $3m-1$ (5, 11 etc.) it is opposite to that of the fundamental. From this it is easily shown that the position of these harmonics in relation to the fundamental of the line voltages is opposite to their position in the phase voltages, so that the waveforms of the phase voltage and line voltage can be materially different, although containing exactly the same harmonics.

The chief interest attaches to the unbalanced currents, *i. e.* to the harmonics of orders divisible by three. Of these we are mainly concerned with the third although the ninth can also sometimes be of importance. The harmonics are greater, the higher the saturation, and are besides more pronounced for alloy sheet than for common dynamo sheet, on account of the sharper knee in the magnetisation curve of the former. This effect is very different in transformers of different kinds and with different arrangements of connections. In the following some of the principal types and schemes of connection will be investigated.

1. *Single Phase Transformers.*

With a Y/Y-connected group of 3 single-phase transformers with low tension neutral connected direct with the neutral point of the generator, it will be clear that the impressed phase voltages will be of pure sine form provided that the generator voltage contains no harmonics. The necessary magnetising current can then be easily determined from the saturation curve of the iron and subjected to harmonic analysis.

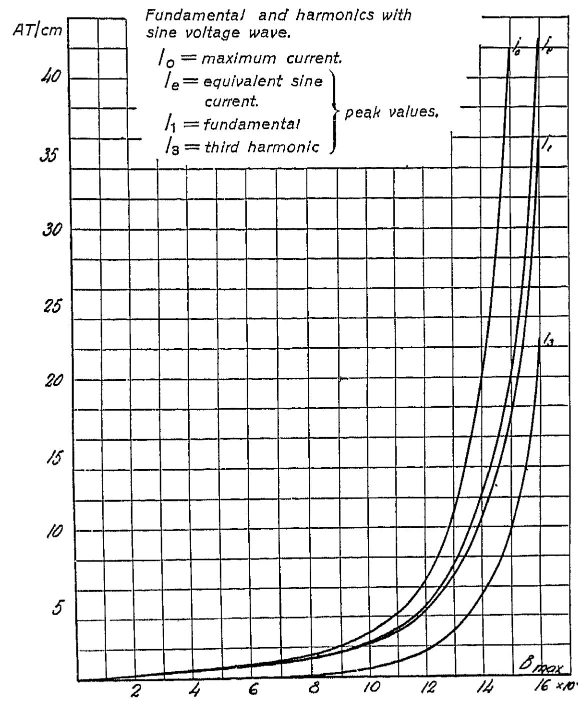


Fig. 1.

The result of such an analysis on the transformer sheet now used by Asea is given in fig. 1 which shows the fundamental and third harmonic as a function of the maximum induction. If instead the transformer group has its primary Δ-connected the behaviour is identical but in this case the third harmonic does not occur in the connections between the generator and the transformers, but flows as a circulating current in the transformers. As far as the generator is concerned there is thus a considerable difference between these methods of connection, since with Y-connection the generator must supply the third harmonic current, while with Δ-connection this is not the case. Disregarding the effect of the reactance of the transformer, which will be more closely investigated later, it is clearly a matter of indifference which of the windings is Δ-connected. If both windings are Δ-connected the third harmonic circulating current will divide itself between the two windings.

The conditions are altogether different in a Y/Y-connected transformer group without neutral point connection. In this case the impressed line voltages are of pure sine form, from which it

follows that the phase voltages cannot contain any other harmonics than those whose orders are divisible by 3. On the other hand the sum of the currents must be zero, and the currents accordingly cannot contain these harmonics, but only harmonics whose orders are not divisible by 3, that is chiefly the fifth and seventh. Liljeblad has calculated the wave forms of voltage and current with this connection for a special case. (Aseas Egen Tidning March 1918, page 35). In the following an exact graphical method is formulated for their estimation.

Since the applied line voltages form a symmetrical three-phase system, this must also be the case with the corresponding inductions B_1-B_2, B_2-B_3 and B_3-B_1. By eliminating time we can easily find from this, if B_0 is the maximum induction corresponding to the fundamental,

$$(B_1-B_2)^2-(B_1-B_2)\,(B_3-B_2)+(B_3-B_2)^2=\frac{9}{4}B_0^2$$

which equation, if B_1-B_2 and B_3-B_2 are considered as variables, represents an ellipse. From the saturation curve we can ascertain further, for different values of B_2, another connection between these variables, and if this connection is shown graphically together with the ellipse we thus obtain B_1-B_2 or B_3-B_2 from the points of intersection between the ellipse and the other curves as a function of B_2. Since

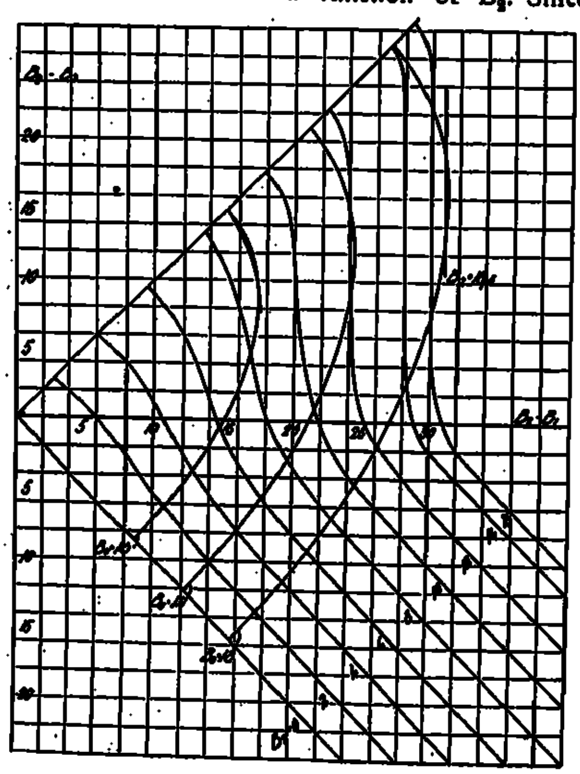


Fig. 2.

B_1-B_2 and B_3-B_2 are known sine functions, we accordingly obtain B_2 as a function of the time. The curves referred to are obtained in the following manner. A certain value of B_2 corresponds to a certain value of the magnetising current i_2 and since due to Y-connection the sum of the currents is zero, to the sum i_1+i_3. From the saturation curve we can now easily obtain the value of B_1 and B_3 for which the sum i_1+i_3 is given. By subtracting the value taken for B_2 we thus obtain B_1-B_2 as a function of B_3-B_2 for this value of B_2. In fig. 2 a series of such curves are given for Asea's standard transformer sheet with ellipses corresponding to $B_0=10{,}000$, 14,000 and 18,000. The B-curves thus obtained have been subjected to harmonic analysis with the results shown in fig. 3. A comparison with actual measurements on a certain transformer gave the following results:

$B_0=$	12,000	14,000	16,000
Measured value e_3/e_1	0.48	0.48	0.57
Calculated do.	0.45	0.52	0.58

As the characteristics of the sheet used in this transformer differ somewhat from that now used by Asea, the agreement may be considered very satisfactory.

We have so far assumed that the leakage reactance of the transformer can be entirely neglected. For a Δ-connected winding this is actually the case, since by reason of symmetry no third harmonic can exist in either line current or voltage. If however the transformer is connected *e. g.* with primary in Δ and secondary in Y a certain third harmonic arises in the secondary phase voltages. As the total flux corresponding to the impressed voltage is of pure sine form, it is clear that the magnitude of this third harmonic is equal to that of the third harmonic in that part of the flux produced by the primary current which does not act inductively on the secondary winding. This flux, which we can call the primary leakage flux, is chiefly propagated through the air and can therefore be assumed to be proportional to the current, and equal to $s \cdot i$, where s is the primary leakage inductance. The third harmonic in the voltage is accordingly equal to $3\,\omega\, s i_3$, where i_3 is the third harmonic in the magnetising current. Putting the magnetising current of the transformer equal to $p_0\, i_n$, where i_n is the normal current of the transformer, and the primary leakage reactance voltage $\omega\, s i_n=p_1 \cdot e$, where e is the normal voltage of the transformer, and lastly the ratio of the third harmonic to the total magnetising current equal to k, we obtain the third harmonic in the voltage $e_3=3\,p_0\,p_1\,k \cdot e$. With a maximum induction of 14,000, in accordance with fig. 1 $k=i_3/i_e=0.444$.

If therefore the magnetising current of the transformer is, for example, 5% and the primary leakage reactance 5% then the third harmonic= 0.33% of the phase voltage of the transformer. If the secondary neutral point of the transformer is earthed, a certain third harmonic current can also exist in the secondary winding through the transformer's load impedance and neutral point connection. In calculating the effect of this current we can approximately regard the reactance of the secondary circuit as connected in parallel with the primary reactance.

If the transformer is Y/Y-connected with the neutral point earthed, the third harmonic current can only find a path through the capacity of the line or through the load to the extent that this is earthed. A calculation of the currents and voltages arising in this way is very involved, but an estimate of the general nature of the phenomenon can be reached by the following approximate method.

As stated above with Y-connection a certain third harmonic is caused in the voltage. If now the neutral points of generator and transformer are connected together this third harmonic voltage disappears, if the leakage reactance is neglected, and a third harmonic current is caused instead. It would thus seem reasonable to regard this current as caused by an electro-motive force in the transformer equal to the voltage arising with Y-connection, which acts across a certain internal reactance, equal to the ratio of that voltage to the current arising with the neutral connected together. Taking into account the leakage reactance of the transformer or the impedances existing in the external circuit, these are regarded as external impedances which are connected in series with the internal reactance of the transformer. The remaining third harmonic in the voltage is then the voltage absorbed in these external impedances. If both primary and secondary windings are so connected that a third harmonic current can occur in them we may regard these two circuits as connected in parallel and in series with the fictitious internal inductance. It is easy to see that this method gives the same result as does the more special method of calculation previously given in the cases where the latter is applicable. If the transformer is Δ-connected and the leakage reactance is small, the third harmonic current arising is, in accordance with this method, practically equal to the third harmonic in the magnetising current with a sine voltage wave, and it follows that the voltage absorbed in the leakage reactance is equal to the voltage drop caused by this harmonic current. For more general cases the method can hardly be controlled otherwise than experimentally.

From the above it will be seen that in making these calculations it is necessary to divide the reactance of the transformer into a primary and a secondary reactance defined in such a way that the primary reactance corresponds to that part of the flux generated by the primary current, which does not act inductively on the secondary winding, whereby the secondary current can be taken to be zero. A corresponding definition applies to the secondary reactance. With only one winding Δ-connected it is clear that the most complete compensation of the third harmonic is obtained if that winding is Δ-connected which has the least reactance. Such a division of the reactance is not permitted by the commonly used reactance formulae, which are based on the resulting flux generated when both windings are traversed by the same current, and would in addition be very difficult to carry out with any exactness. By regarding some special transformer types we can arrive at some idea as to the way in which the reactance should be divided in the two windings. For a transformer with a core of ring shape, such as is sometimes employed for current transformers, and having one winding evenly distributed on the core all the flux caused by the current through this winding also acts inductively on the other winding, *i. e.* the leakage reactance of the inner winding is in this case zero. This would be the case for an ordinary transformer if the yoke were spread out into a plane at the ends of the windings and if the windings were carried right up to this plane. In this case of course all the flux lines excited by the inner winding would pass through this winding and complete their circuit through the yoke, so that they would all act inductively on the outer winding also. From this it follows that in an ordinary transformer the reactance

Third harmonic in voltage and flux with Y connection.

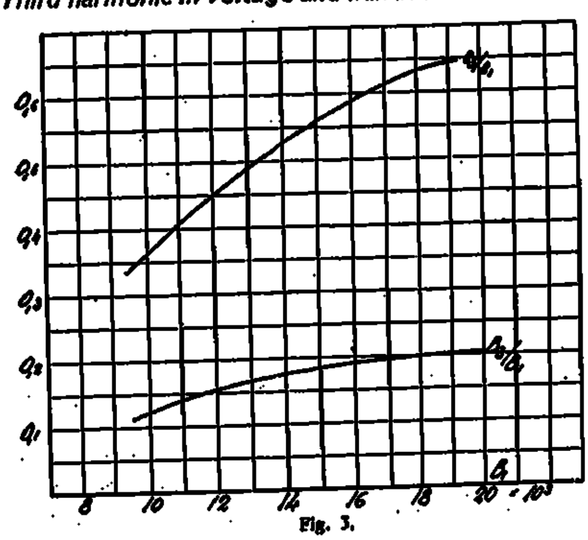


Fig. 3.

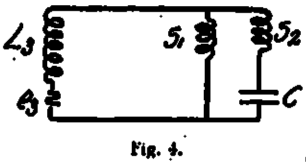


Fig. 4.

of the inner winding is due exclusively to end effects, and as these end effects can be neglected in ordinary reactance calculations with good results it is to be expected that the reactance of the inner winding is small in comparison with that of the outer winding. In general accordingly the best possible results will be obtained by Δ-connecting the inner winding, *i. e.* in the majority of transformers the low tension winding.

As mentioned before, the remaining third harmonic is very considerably affected by resonance phenomena, between the transformer and the line supplied by it. Applying the approximate method of calculation described to this problem we obtain an equivalent scheme of connections to that shown in fig. 4. It is seen from this that if the transformer has Δ-connected primary and Y-connected secondary with earthed neutral point, resonance occurs when the leakage reactance of the transformer is in resonance with the capacity of the line. With resonance the external reactance becomes infinitely great, the resulting third harmonic current becomes zero, and the resulting third harmonic voltage is equal to the voltage which arises with Y-connection without earthed neutral. If on the other hand the transformer has Y-connected primary without neutral connection, resonance occurs when the above defined fictitious reactance is in resonance with the line capacity. Since this reactance is always considerably greater than the leakage reactance of the transformer, resonance takes place in this case with a considerably shorter line. The following numerical example may assist in explaining these conditions.

Consider a transformer group of 5,000 kVA, 50 kV, 50 periods to have 5% no-load current and 5% short circuit voltage, corresponding to a no-load reactance $X_0=10{,}000$ ohms and a short circuit reactance $X_k=25$ ohms. Assuming the flux density is 14,000 the fictitious internal inductance is 0.394 times the no-load inductance, or $X_s=3\cdot 0.394\ X_0=11{,}800$ ohms. The leakage reactance to the third harmonic is $X'_k=3X_k=75$ ohms. The no-load capacity of the line to the third harmonic is of the magnitude

$$X_c=800\cot\frac{\pi L}{1{,}000}$$

where L is the length of the line in km. With Δ-connection resonance is obtained when $X'_k=X_c$, which occurs with $L=475$ km, and with Y-connection when $X_s=X_c$, or for $L=22$ km.

In the last case particularly this simple method of calculation is not sufficiently exact for a proper analysis of these phenomena, but it shows that with Y-connection we may expect, with rather short lines, a considerable increase in the third harmonic due to the action of capacity.

II. *3-phase Core type Transformers.*

In three-phase core type transformers the conditions are very different on account of the magnetic coupling between the different phases. The third harmonic flux which lies in phase in all three legs of the transformer can accordingly only complete itself through the air and through the transformer tank, and as the magnetic reluctance through this path is very large compared with the reluctance of the legs, it may be expected that only a negligibly small third harmonic flux can exist in such transformers. On the other hand as far as the transformer is concerned these fluxes may be of much greater importance than in a single-phase transformer on account of the eddy current losses caused by them in the transformer tank. The phenomenon is further complicated by the fact that a 3-phase core transformer is not symmetrical as regards its three phases because of the necessary magnetising current for the yoke.

For calculation, denote by

$i_1\ i_2\ i_3$ the magnetising currents for the three phases, of which 1 and 3 denote the outer phases, 2 the middle phase.

$I_1\ I_2\ I_3$ the requisite magnetising currents for the three legs.

$I'_1\ I'_3$ the requisite magnetising currents for the yoke.

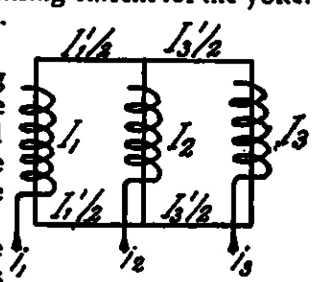


Fig. 5.

Then according to fig. 5.

$$I_1+I'_1-I_2=i_1-i_2 \qquad (1)$$
$$I_3+I'_3-I_2=i_3-i_2 \qquad (2)$$

With Y-connection the sum of the currents must, further, amount to zero, *i. e.*

$$i_1+i_2+i_3=0 \qquad (3)$$

From these equations the currents are easily calculated as follows

$$\begin{aligned} i_1&=I_1-\frac{1}{3}(I_1+I_2+I_3)+I'_1-\frac{1}{3}(I'_1+I'_3)\\ i_2&=I_2-\frac{1}{3}(I_1+I_2+I_3)\qquad\;\; -\frac{1}{3}(I'_1+I'_3) \qquad (4)\\ i_3&=I_3-\frac{1}{3}(I_1+I_2+I_3)+I'_3-\frac{1}{3}(I'_1+I'_3) \end{aligned}$$

The two first terms represent the magnetising current of the legs reduced by the harmonics

whose orders are divisible by three, the remaining terms show the distribution of the magnetising current of the yoke between the three phases. It is interesting to establish that in spite of Y-connection, third harmonics for these components exist, although as balanced currents. The vector diagram for the currents has the appearance shown in fig. 6. Assuming for example $I' = 0.8\ I$, we obtain for the fundamental and harmonics having orders not divisible by three, $i_1 = i_3 = 1.68\ I$, $i_2 = 1.27\ I$. i_1 and i_3 are rotated 7.9° from the directions corresponding to those of symmetrical three-phase currents. The third harmonic in the middle phase is twice as great as, and directly opposed to, the third harmonics in the two outer phases.

With Δ-connection or Y-0-connection we cannot ignore the possibility of a field through the air, for if this is neglected we can add to the currents with Y-connection an arbitrary neutral point current equally divided between the three phases without any alteration in the field arising, since these currents can only excite a field which is completed through the air. We must therefore assume that a certain flux in the air, proportional to the magneto-motive force between the yokes, can exist. Since however this m. m. f. is not constant over the whole yoke we introduce a mean value I_0 of the m. m. f. at the points where the legs join the yoke and put accordingly

$$(c+2)\,I_0 = i_1 - I_1 + c\,(i_2 - I_2) + i_3 - I_3 \ldots\ldots\ldots (5)$$

$c = 2$ should correspond to the condition that with uniform m. m. f. the flux in the air proceeds uniformly from the yoke. On account of the extra surfaces at the ends of the yoke and also to the possible effect of the tank, this is not exactly the case, but c has a value which is probably somewhat less than 2.

Equation (5) also makes possible an estimation of the air flux with Y-connection since by putting in expression (4) for i we obtain

$$-3\ I_0 = I_1 + I_2 + I_3 + \frac{c-1}{c+2}\,(I'_1 + I'_3) \ldots\ldots\ldots\ldots (6)$$

The m. m. f. which causes the flux through the air accordingly consists partly of a third harmonic in the magnetising currents of the cores, and partly of a proportion of the magnetising current for the yoke, which is zero if $c = 1$.

With Δ-connection it is clear that the flux in the air and accordingly I_0 must be zero, since the sum of the applied voltages is zero. Equation (5) therefore gives the third equation, which together with (1) and (2) determines the currents. If these are divided into a balanced component i'_1, i'_2, i'_3, and a neutral point current i_0 evenly divided between the three phases so that $i_1 = i'_1 + \frac{1}{3}\,i_0$ etc., the same expression is obtained for the balanced components as for the total currents with Y connection, and

$$i_0 = I_1 + I_2 + I_3 + \frac{c-1}{c+2}\,(I'_1 + I'_3) \ldots\ldots\ldots\ldots\ldots (6)$$

i. e. in each phase we must add a current equal to the m. m. f. between the yokes with Y-connection.

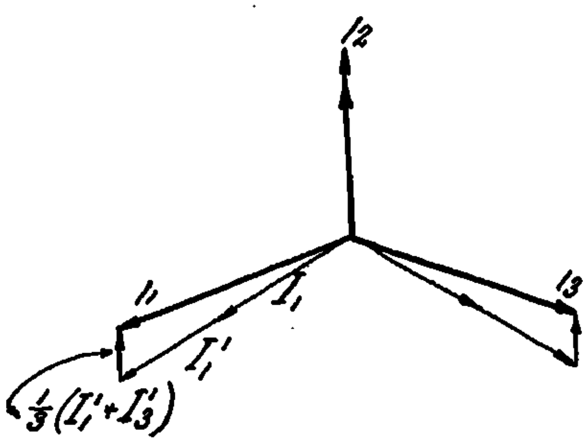


Fig. 6.

Assuming as before $I' = 0.8\ I$ and further $c = 2$ we obtain $i_0 = 0.2\ I$, $\frac{1}{3}\,i_0 = 0.067\ I$. This is 180° out of phase with the magnetising current in phase 2 and we obtain $i_1 = i_3 = 1.70\ I$, $i_2 = 1.20\ I$. i_1 and i_3 are displaced 7.1° from their symmetrical positions.

It can easily be shown that the approximate method for the calculation of the effect of the external circuit for single phase transformers is very accurate for three-phase core type transformers. On account of the very small value of the neutral point voltages we shall not go further into this. The following tests made on an air-cooled transformer of older type without tank give an idea of the voltages which can be expected to arise. By exciting all three phases in parallel with single-phase current the reactance of the transformer per phase against a flux going through the air was found to be 4.74% of the normal no load reactance. Assuming the flux density to be 14,000 the third harmonic in the current, *i. e.* the m. m. f. to be expected between the yokes, has a magnitude 0.5 times that of the fundamental, and thus the third harmonic flux through the air is $0.5 \cdot 4.74 = 2.37\%$ of the total flux, and the third harmonic in the voltage is $3 \cdot 2.37 = 7.1\%$ of the phase voltage.

CONDENSER BUSHINGS.

I. *Principle of Construction.*

Every bushing is a condenser in which the bolt acts as the inner plate, and the supporting sleeve as the outer plate. One of the simplest types of bushings is the one made of solid paper as shown in fig. 1. The sleeve is a thin metal cylinder or a thin metal sheet with a shrunk on flange. The greatest electrical stresses are at the surface of the bolt (radius r_o), and at the ends of the outer metal covering (radius r_n). Both of these places are made as far as possible airtight and embedded in paper, the dielectrical strength of which is considerably greater than that of air. In calculations for such a bushing the ordinary equation for cylindrical condensers is used:

Let V= the voltage between bolt and flange,
E= the strength of the radial electric field inside the cylindrical condenser.
r = the distance of a given point from the axis of the cylinder.

Then:

$$E=\frac{V}{r ln \frac{r_n}{r_o}}$$

The strength of the radial field is accordingly inversely proportional to the distance from the axis, and the greatest and least stresses are in the same ratio as the outer and inner radii. A further characteristic of the bushing described is the great alteration which takes place in the strength of the tangential field, along the length of the insulator surface between the bolt and the supporting flange. The particularly strong field concentration at the ends of the metal covering, and the corresponding high tangential field strength reduces the flash over voltage for this type, and this determines the economic voltage limit for this construction, which lies at a flash-over voltage of about 200 kV.

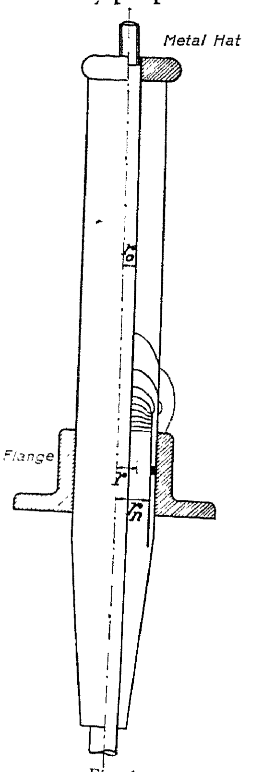


Fig. 1.

From the arrangement shown in fig. 1, a »condenser bushing» is developed (fig. 2) if one or more tinfoil layers, in general $n-1$, are placed between the bolt and the outer supporting covering. The bushing then consists of n cylindrical condensers in series having radii r_o and r_1, r_1 and r_2..., r_{x-1} and r_x..., r_{n-1} and r_n, and lengths l_1, l_2..., l_x..., l_n. The designer must aim at making this distribution, so that, by the use of the least possible material, the best possible distribution of the radial and axial components of the electrical field is obtained. In order to accomplish this it is necessary to have the closest knowledge of the properties of the materials used and the methods employed in manufacture.

II. *Physical and Chemical Properties of Bakelite Paper, and the Methods of Manufacture necessary in its use.*

The material used for condenser bushings is bakelite paper *i. e.* paper wich has been coated with synthetic resin. Synthetic resins are condensation products of phenol and formaldehyde. They were introduced into the electrical industry in 1909 by Bakeland under the name of bakelite. According to Bakeland, bakelite occurs in three different grades, viz: as the primary product A, the intermediate product B and the final product C.

Bakelite A is easily melted, and is soluble in alcohol. By heating, it is transformed in giving off water into bakelite B which is insoluble and can be softened by heating, but which does not melt. By continued heating bakelite B changes into the stable final product C. Unlike shellac this cannot be melted or softened. It is further insoluble even in alkaline solvents, is non-hogroscopic, and is not affected by dilute acids. Besides this, bakelite C is a valuable heat-resisting insulating material, which is not charred before a temperature of 300° C is reached, and then does not burn.

For the production of bakelite paper, bakelite A is dissolved in alcohol, and brushed on to the paper, which is afterwards slowly dried. As the paper is not adhesive when it is cold,

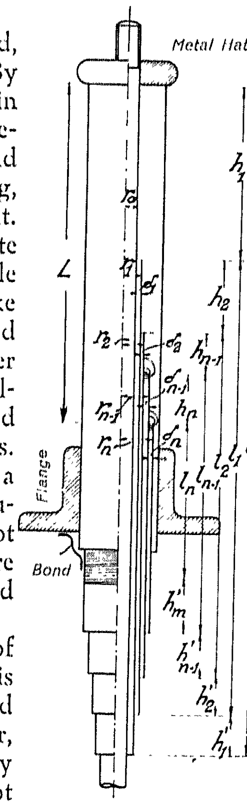


Fig. 2.

it can be made into rolls and stored in this manner. The insulators themselves are, however, made by winding the paper from small rolls about 6 cm wide, and are wound spirally with a narrow overlap, or alternativly from rolls having a breadth equal to the total length of the insulator, which is then wound cylindrically on the bolt. The first method is used by Asea for long insulators, and the last method for short ones. In both cases the rolls are submitted to a further thorough drying process before being placed in the winding machine. During winding the stretched paper is pressed by heated rolls on to the core, so that the bakelite softens into a tough india-rubber like substance, and the remains of the solvent as well as any water present is evaporated. At the same time it is advantageous to have the greatest possible tension on the paper, and this makes it necessary to use paper which is of a very high quality. The paper employed by Asea in the unimpregnated state has a tensile strength of about 30 kgs on the width, the thickness being 0.07 mm.

After the rolling procedure the insulator is baked in a vacuum oven at about 115° C and dried in vacuum for from one to two days, so that the bakelite is changed into the final product C. As this change when taking place at atmospheric pressure, or lower, gives rise to gas formation, many firms carry out the baking under a pressure of from 8 to 12 atmospheres which impedes the formation of blisters. After comparison with the foreign product the vacuum process has been found by Asea to be at least as good as the pressure process, at any rate when the Asea patent micanite interleaving is used, the elasticity of which considerably eases the escape of the gas formed. Possibly also there is, in spite of the vacuum outside, a sufficiently high pressure on the inside due to the shrinking of the paper. In any case experience indicates that the use of the vacuum process is an advantage since the quality of the condenser bushing depends to the greatest extent on the dielectric losses, which are influenced by the moisture remaining more than by any other factor, and the vacuum process is the best drying process known. How far improvement in bushings can be obtained by a combination of the pressure and vacuum processes it has been, at present, impossible to determine with certainty.

After drying and baking the insulator must be protected against damp. The synthetic resin is not hygroscopic, but the paper absorbs moisture. By careful varnishing the resistance of the finished insulator to damp can be made very considerable. The absorbtion of moisture is also limited to the outer layer, and can be driven off again by drying with hot air. The protection given by varnish is accordingly sufficient for the oil side of the transformer bushings. For the side which is in the air it is best to protect the insulator with a porcelain cover, so that the bushing can be run in airtight with a cable compound having high electrical properties. When an insulator is to be used in the open air, this method of protection is absolutely necessary (fig. 3).

III. *The Electrical Properties of Bakelite Paper and the Limits imposed by these as regards large Condenser Bushings.*

The calculation of condenser bushings is governed by two points of view: regard to the dielectric strength of the bakelite paper, and to the dielectric losses.

When speaking of dielectric strength we mean something entirely different from that breakdown voltage, which can be determined in the laboratory on paper tubes of small thickness.

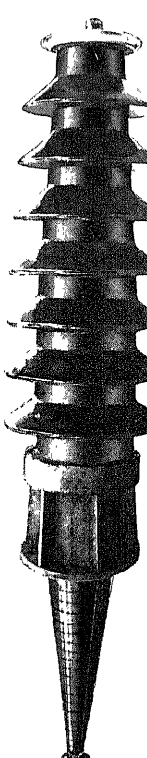


Fig. 3.

These laboratory values are of no use for dimensioning and testing of condenser bushings. For every cylindrical condenser, in a condenser bushing one must deal also with the electrical field at the edges of the cylinders (the tinfoil layers). With a given radial field strength, $E_{xr} = \frac{V_x}{r_x - r_{x-1}} = \frac{V_x}{\delta_x}$ (fig. 2) this field concentration is proportional to the square root of the thickness of the layer ($\sqrt{\delta_x}$). The larger the number of separate condensers the smaller the field concentration becomes. Partly for this reason, and partly for reasons of simplicity in manufacture, all these layers are made by Asea with a constant thickness $\delta_x = \text{const.} = 3$ or 3.5 mm which has been shown to be a sufficiently small value. Only the outer layers are made of less thickness (2.5 or 3 mm) as in this position the strength of the radial field can, without disadvantage, be allowed to have a considerably higher value than the field strength at the middle (Cf. Sect. I). If we keep increasing the field strength between adjacent tinfoil layers a point is reached finally when brush discharge occurs on

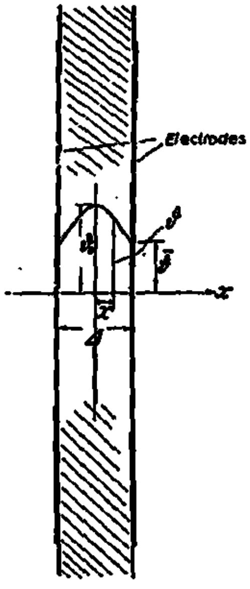


Fig. 4.

account of a too great concentration of field at the tinfoil edges, which are never entirely free from the presence of gas. The limiting voltage for this phenomenon is of course higher the tighter the bushing has been wound. It seems however that it can never be entirely avoided. The discharge gives rise to a slow but still sure deterioration of the material and this must at all costs be overcome. Regard for this point accordingly limits the radial field strength and it has been found most suitable not to have this higher than 30 kV/cm. With Asea's standard design the average field strength is about 18 kV/cm or less with normal working voltage (line voltage) so that brush discharge need not be feared even if the bushing is not particularly tightly wound.

Brush discharge is stronger, with a given radial strength, the higher the axial mean field strength $E_m = \frac{V_x}{h_x}$ is made (h_x is the height of step in accordance with fig. 2). In addition the dielectric strength in the direction of the layer is much less than it is at right angles thereto. It appears as if the gases enclosed between two layers can be ionised comparativly easily by a strong voltage drop in this direction so that an insulator in which the axial field strength is too high will flash over, not in the air outside the insulator body, but in the insulator body itself along the ionised layer. To prevent such internal flash over even when the winding is not perfectly tight the strongest axial field strength in standard Asea bushings is limited to about 6 kV/cm with the pressure applied when testing for flash-over.

While limitations just indicated are not associated in any way with the material used there is another constant, depending on the material, which exercises a most important effect on the breakdown strength of a condenser bushing, namely the dielectric losses. The fact that nearly all the breakdowns occurring in practice are the result of overheating in the insulating material appears to be quite recently recognized abroad. (Cf. K. W. Wagner's much observed publication: The physical nature of the electrical breakdown of solid dielectrics. Transactions of the A.I.E.E. 1922, vol. 41).

In Asea the knowledge of these characteristics is relativly old. The occurrence of insulation failure led to a preliminary theoretical investigation of the breakdown limit and a continuous testing of dielectric losses experimentally. For several years back no insulators have left the high-tension shops at Ludvika without having undergone test for losses, and to our knowledge no breakdowns at all have occurred among the insulators tested in this way. During the same period research has gone on continuously, and with the best results, with a view to making bakelite paper better and cheaper.

The reason that the dielectric losses are so dangerous to the life of paper bushings lies in two characteristics of the material. The first is the rapid increase in the losses with rising temperature (especially with the high oil temperatures which arise in selfcooled transformers) and the second is the poor heat conductivity of bakelite paper. A mathematical investigation will show us what important connections follow from this.

Assume that we are testing a flat sheet of pressed bakelite paper between tinfoil electrodes in a warm oil bath. The surfaces of the electrodes are so great in comparison with the thickness of the sheet that over a large area the conduction of heat takes place practically at right-angles to the surface of the sheet (x direction). Further we have (fig. 4):

$\bar{\vartheta}$ °C	the temperature of the electrodes which, as a first approximation, can be taken to be the same as the temperature of the oil bath, and
ϑ_0 °C	the max. temperature in the midplane of the sheet,
$\lambda \frac{\text{watts}}{\text{cm}^2\,°\text{C/cm}}$	the coefficient of conductivity of heat for the material of the sheet,
$p \frac{\text{watts}}{\text{cm}^3}$	the losses with a certain field strength $E = \frac{V}{\Delta}$ kV/cm and a certain temperature ϑ
$\bar{p} \frac{\text{watts}}{\text{cm}^3}$	the losses for the surface layer immediately under the electrodes,
$p/\bar{p} = \varphi(\vartheta)$	the important function which gives the growth of the losses with the temperature.

Then we obtain the equation for heat distribution when stable conditions have been reached

$$\lambda \frac{d^2\vartheta}{dx^2} + \bar{p} \cdot \varphi(\vartheta) = 0 \quad \ldots\ldots\ldots\ldots\ldots (2)$$

This equation can be generally integrated and gives for the max. temperature ϑ_0 as a function of the thickness of plate Δ the implicit equation

$$\psi(\vartheta_0, \bar{\vartheta}) = \sqrt{2}\int_{\bar{\vartheta}}^{\vartheta_0} \frac{d\vartheta}{\sqrt{\int_{\vartheta}^{\vartheta_0}\varphi\, d\vartheta}} = \Delta\sqrt{\frac{\bar{p}}{\lambda}} \quad \ldots\ldots (3)$$

From this equation we are able to read 3 important results:

1) Sheets of arbitrary thickness Δ and with the same surface temperature $\bar{\vartheta}$ have the same highest temperature ϑ_0, provided that they agree in the »characteristic temperature»

$$\vartheta_k = \Delta^2\frac{\bar{p}}{\lambda} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

2) It can be shown that the function $\psi(\vartheta_0, \bar{\vartheta})$ has a maximum $\psi_{max.}(\bar{\vartheta})$ at a certain highest temperature ϑ_{om} for a given surface temperature, provided that the function φ increases continuously as the temperature increases. The meaning of this is as follows: If a stable temperature distribution is to be obtained inside the sheet, the interior temperature must never exceed ϑ_{om}. In other cases no state of heat equilibrium is possible, but the temperature of the sheet will increase until it breaks down. Having regard to this new result we put:

$$\Delta_{max.} = \sqrt{\frac{\lambda}{\bar{p}}}\psi_{max.}(\bar{\vartheta}) \quad \ldots\ldots\ldots\ldots\ldots (5)$$

This is the greatest thickness of sheet with which stable conditions can be obtained, given a surface temperature $\bar{\vartheta}$ and a loss figure $\bar{p}$.

3) The loss figure $\bar{p}$ can be expressed in terms of the field strength $E = \frac{V}{\Delta}$, e. g. by on exponential law

$$\bar{p} = \chi(\bar{\vartheta})\,\bar{E}^n = \chi(\bar{\vartheta})\frac{V^n}{\Delta^n} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Inserting this in equation (5) we obtain:

$$V_{max} = \Delta^{\frac{n-2}{n}}\sqrt[n]{\lambda\cdot\frac{\psi^2_{max.}(\bar{\vartheta})}{\chi(\bar{\vartheta})}} \quad \ldots\ldots\ldots\ldots (7)$$

$$V_{max} = \Delta^{\frac{n-2}{n}}\sqrt[n]{\lambda\frac{\bar{E}^n}{\bar{p}}\psi^2_{max.}(\bar{\vartheta})} \quad \ldots\ldots (7a)$$

We have thus established the law by which the breakdown voltage increases with the thickness of the sheet, a law which, in spite of its great practical importance, seems to be hithertoo unknown.

We are obliged, from considerations of space, to refrain from a general discussion of equations 7 and 7a and confine ourselves to what is important for the understanding of condenser type bushings. In this respect interest is concentrated on the one question: Have the material constants n, λ, ψ and χ such values that $V_{max.}$ can be less than any of the voltages at present in use?

As far as the first coefficient n is concerned, condenser bushings are worked at such low field strengths that the losses can be taken as proportional to the square of the field strength. But for $n = 2$ the thickness of layer disappears in equation 7. If therefore V_{max} is a limiting voltage for bushings this may not be raised (with a given outer temperature) by enlarging a bushing which is to scantily designed, uniformly in all parts. Certainly the field strength and losses are thereby reduced; but the simultaneous reduction in the heat conduction discounts this advantage. The only difference is that the larger bushing resists the same voltage for a somewhat longer time than the smaller one. The highest possible working voltage is therefore a function, not of the dimensions, but of the external temperature and the quality of the material.

We now introduce into the calculation the characteristics for a good quality bakelite paper and at the same time alter equation 7 established for sheets, so as to give it the correct constants for the cylindrical problem of condenser bushings. We then obtain (for $n = 2$)

$$V_{max}^{kv} = 115\sqrt{\frac{100\,\lambda\,(\bar{E}/10)^2}{100\,\bar{p}\cdot 100\,\gamma}}, \quad \ldots\ldots\ldots\ldots (8)$$

the increase in the losses with the temperature being expressed in the following manner:

$$p = \bar{p}\cdot e^{\gamma(\vartheta-\bar{\vartheta})}$$

Putting now for insulators in oil at 80°:

$$\bar{p} = 0.00255 \text{ watt/cm}^3$$

for $\bar{E} = 20$ kV/cm,

($\bar{E}$ and $\bar{p}$ can actually be less provided the ratio $\bar{E}^2/\bar{p}$ is maintained constant), and further

$$\gamma = 0.0215 \ 1/°C$$

$$\lambda = 0.00165\,\frac{\text{watt}}{\text{cm}^2\frac{°C}{\text{cm}}},$$

we obtain:

$$V_{max} = 115\sqrt{\frac{0.165\cdot 4}{0.255\cdot 2.15}} = 126 \text{ kV}.$$

With earthed neutral this corresponds to a line pressure of 220 kV, which is certainly a very high voltage, but it must be remembered that we have made use of material constants which represent exceedingly good material and workmanship. We see how important it is in every case to reduce the loss figure and temp-

erature coefficient of the material used. Asea's patented method of inlaying mica has shown itself to be a very good means of accomplishing this. Mica has very small specific losses and low temperature coefficient. These mica layers, and other innovations in construction, as well as a continuous check on the losses now enable Asea to supply condenser bushings, both for leading through wall insulators and for transformer terminals in contact with hot oil, for working voltages up to double the limiting pressure calculated above.

IV. *The calculation of condenser bushings.*

Mathematical treatments are sometimes found in technical literature for the most favourable dimensioning of condenser bushings without the slightest reference to the very great importance of the properties of the materials. Such articles only show that their authors do not know where the real difficulties lie. If we keep within the limits given above for the radial and axial field strengths, then, with good materials and good workmanship, good bushings will always be obtained. We shall accordingly not give any actual designing rules but only subjoin some remarks regarding the flash-over voltage of our insulators.

Asea's condenser bushings are so designed that in the dry state they flash-over at the end in the air, at some distance from the insulator surface, without any previous brush discharge or running sparks. This is attained by embedding the edges of the tinfoil (at the air end) in paper or compound, and the use of a uniformly low tangential field stress on the air side. It was previously thought that the axial field strength should be kept constant along the whole flash-over path in order to obtain the highest possible flash-over pressure and the shortest possible bushing. On the oil side this is unquestionably to be advised. On the air side we only obtain an advantage if at the same time we provide the fixing flange of the bushing with corners of very large radius and also make these flanges very big. Investigation has however shown this to be uneconomical. But as flash-over with ordinary end flanges is always prefaced by breakdown of the air at the flange, there is no object in working with a constant axial field strength, if it is found that variable field strength gives more favourable dimensions for the bushing. Asea accordingly keeps the radial field strength as far as possible constant without exceeding the limits already given for the axial field strength, and in this way obtains bushings with minimum length and minimum losses. The flash-over pressure of these bushings commonly lies from 10 to 20 kV above the value permitted by the Swedish standard rules. The length of their flash over path L (see fig. 2) is approximately

$$L = 0.69 \cdot V,$$

where V denotes the line voltage.

FRONT PAGE.

On the front page of this number we illustrate the interior of the Norwegian State Power Station of Glomfjord, one of the most northerly large power stations in the world. This station is just above the Arctic Circle in Northern Helgeland, at the head of one of the Norwegian fjords on the Atlantic coast. The waterpower is obtained from a river, which is chiefly fed by rainfall in the glacier Svartisen. At the present time about 80,000 h.p. have been utilised. The station was completed in 1919, and was equipped by Asea with two three-phase generators, each of 22,000 kVA at 300 r.p.m., 25 cycles and 15,000 volts, together with complete switchgear etc. Three years later a further generator was supplied, which was generally of the same type, but designed for an utput of 24,000 kVA.

These generators are among the largest which have been supplied in Europe for direct coupling to water turbines. As the illustration shows, they are totally enclosed machines, and are placed with their shafts longitudinally in the machine room. The external dimensions of the machines are of course noteworthy. The stator diameter externally is 6.7 metres, the axial length from the coupling flange to the end of the exciter is 7.4 metres, and the breadth over the stator feet 8.4 metres. Each generator weighs approximately 225 tons, of which the rotating parts account for about 95 tons.

Besides their large size, these generators are interesting on account of the high voltage. This was chosen in order to do away with the necessity for transformers when transmitting the power to the neighbouring industrial district of Haugvik, where a large part of the energy is used. With the exception of two medium sized generators for 20,000 volts working pressure which Asea constructed about 20 years ago, these generators are designed for the highest machine voltage in use in Scandinavia. Special care was given to the design of the stator winding, and the construction adopted has withstood all the stresses thrown upon it during the time the machines have been running.

Vesteras 1925, Vestmanlands Allehanda Printing Co.

ASEA-JOURNAL

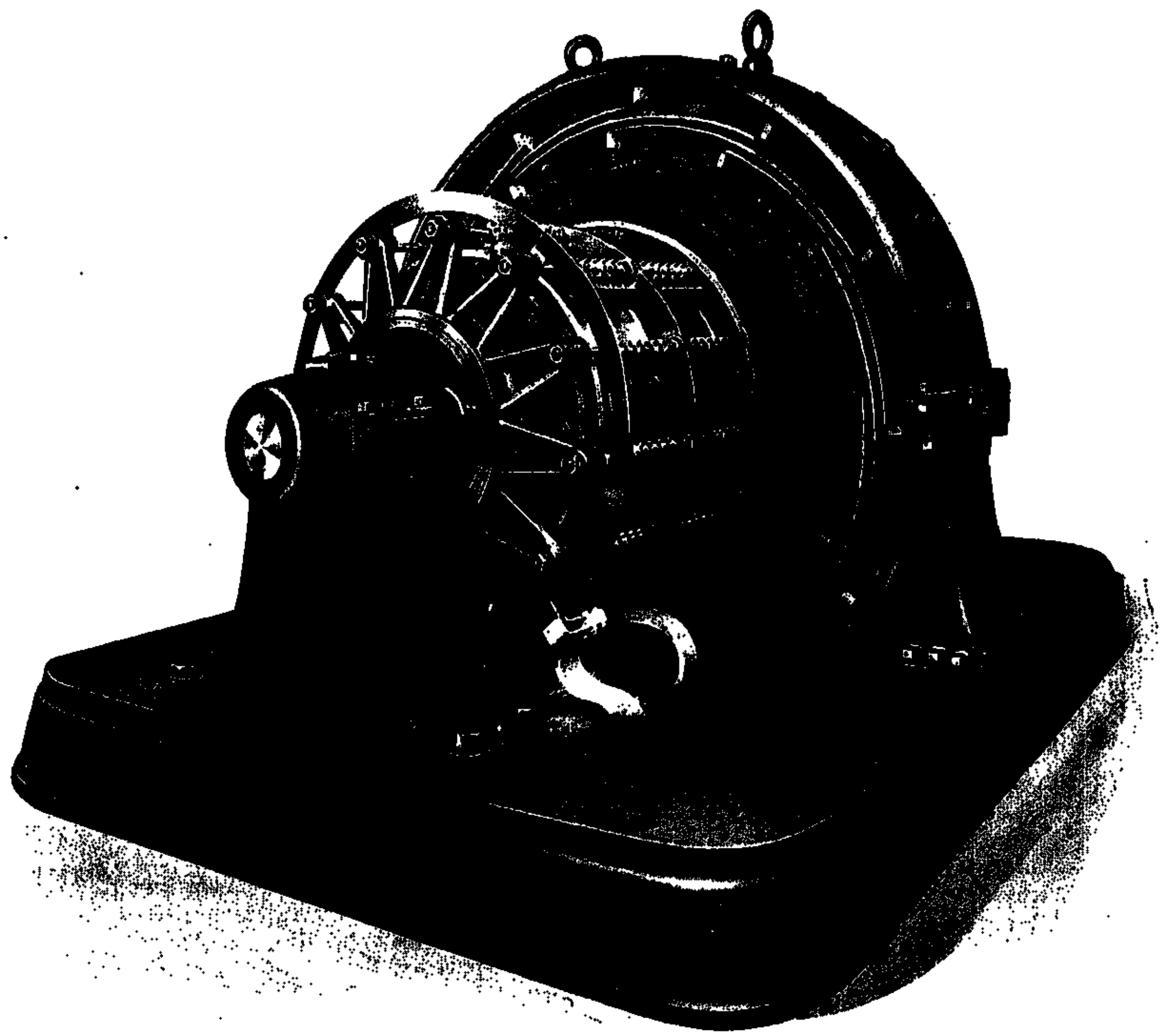
ALLMÄNNA SVENSKA
ELEKTRISKA A.B.
VESTERAS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

VOL. II
1925

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesteras, Sweden.
Permission is given to reprint articles or extracts from this journal,
on condition that the name — Asea-Journal — is clearly stated.

DECEMBER
No. 12



1,500 kW rotary converter, 50 cycles three-phase — 460 volts DC.

MECHANICAL STRESSES IN THE WINDINGS OF CORE TYPE TRANSFORMERS.

By far the most common fault in transformer windings is the occurrence of a short circuit between neighbouring turns of the same winding. As such faults obviously occur because the insulation between turns is not able to withstand the electrical pressures which arise, it is not to be wondered at that excess pressures of more or less mystical nature are blamed for the trouble. The remedy, it follows, has rightly been strengthened turn insulation, and this has brought about a decided falling off in the number of short circuit faults. By critical investigation of the construction of transformers which have shown especially high, or low, percentages of breakdowns, and by direct experiments we have, however, been able to substantiate:

that insulation between turns which is free from mechanical faults is surprisingly resistant to excess pressure waves,

that insulation between turns protected from mechanical damage by suitable forming, or by some special method of manufacture, showed high reliability as regards short circuit breakdowns, in spite of the relatively weak insulation used in accordance with modern practice,

lastly, transformer windings, unsuitable in the mechanical respect, in spite of heavy turn insulation, gave rise to a large number of short circuit breakdowns.

From such observations it may readily be concluded that mechanical stresses in transformer windings, and not the excess voltages, are responsible for many short circuit failures. In our view an overwhelming number of coil breakdowns are caused primarily by mechanical injury to the insulation between turns; not until the turn insulation becomes weakened through mechanical action does electrical breakdown occur. A strengthening of the insulation between turns certainly gives increased protection against mechanical damage. As however the insulating material used for turn insulation is always more or less fragile in the mechanical respect, and above all as excessive turn insulation makes the provision of compact and mechanically stable coils impossible, it is clear that improvement in the safety of transformer windings against short circuit breakdowns is not to be attained by increasing the insulation only. Precautions must also be taken at the same time to prevent, as far as possible, the occurrence of dangerous mechanical stresses in the windings.

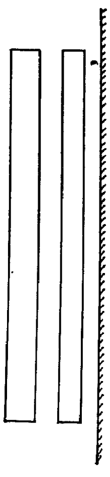


Fig. 1.

The intention of this article is to give a simple description of the nature and magnitude of the mechanical stresses occuring in the windings of a transformer under unfavourable running conditions. The treatment is restricted to cover core type transformers with concentric cylindrical windings only, since transformers of this type greatly predominate at the present time. In a core transformer with concentric cylindrical windings the two windings are placed beside each other along the core as in fig. 1. Apart from the current necessary for magnetising the core the two windings carry an equally large volume of current, in opposite directions, corresponding to the load. In the circular interspace between the windings, and in the windings themselves, these currents produce a flux, the load current magnetic flux or leakage flux, which is propagated approximately as shown in fig. 2. Due to the fact that the extent of the windings in the axial direction is considerably greater than their extent in the radial direction, only a small error is introduced if we assume that the leakage flux runs quite axially in accordance with fig. 3.

In calculating the voltage drop caused by the leakage flux in transformers, the reactance voltage, the formulae used are based on this assumption, namely that the leakage flux runs in accordance with fig. 3. Further, in these formulae, the reluctance of that part of the leakage flux circuit which runs outside the windings is also neglected. As calculated values for the reactance voltage with a symmetrical arrangement of windings, such as we are now considering, always show very good agreement with the values actually measured, it is clear, that the leakage lines, which cut the windings in accordance with fig. 2, altogether represent only a very inconsiderable flux. We now examine the mechanical stresses acting on the windings which are caused by interaction between the (leakage) flux existing at every part of the winding and the currents. The approximate leakage flux in accordance with fig. 3 clearly only gives mechanical stresses in the radial direction which in accordance with well-known rules endeavour to separate the two windings from one another. The outer winding is sub-

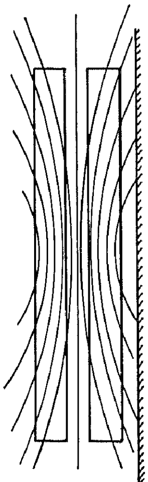


Fig. 2.

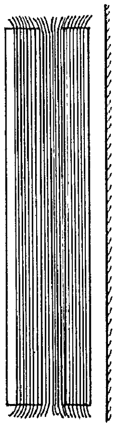


Fig. 3.

jected to a stress analogously to a tube under internal pressure while the stress on the inner winding corresponds to a tube under external pressure. With the above assumption for the calculation of the strength of the leakage flux we obtain a flux distribution in accordance with fig. 4. The maximum flux density occurs between the windings and is

$$H = \frac{0.4\, \pi\, N\, i}{h}$$

where N is the number of turns in the winding, i the maximum current strength in amps. in each of the windings, and h the height of the windings in cms. In the windings themselves the flux density decreases as a straight line from the intervening space between the windings to a value 0 at the opposite side. The mean flux density for each winding is accordingly half of this value and the total radial stress per cm length of conductor and cm of winding is

$$p = 1.02 \frac{N\, i \cdot H}{h\, 2} \cdot 10^{-7} \text{ kg.}$$

These stresses p act in the radial direction on a cylindrical coil. The resulting tractive force per cm height of winding is

$$\triangle P = p \cdot \frac{D}{2}$$

where D approx. is the mean diameter of the winding in question. The total hoop stress on the whole winding is thus

$$P = \frac{p \cdot D \cdot h}{2}$$

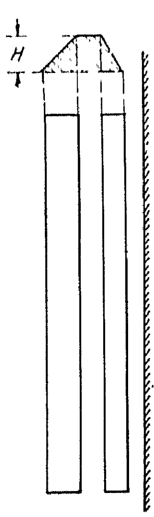


Fig. 4.

In a certain transformer the total number of load amp. turns per winding is 28,000 eff. amp. with max. value 39,600; the height of winding, h, is 110 cm. From this is calculated $H = 452$ cgs, $p = 8.30 \cdot 10^{-3}$ kg. The hoop stress $\triangle P$ is, for the high tension winding, with mean diameter 57.5 cm 0.24 kg and for the whole winding $P = 26.2$ kg. This stress is very small, but is valid only under normal working conditions. The short circuit voltage of the transformer in question is 6 %. With a symmetrical short circuit on full voltage accordingly the symmetrical short circuit current would reach 16.7 times the normal value, and the mechanical stresses 16.7^2 times the normal value. Further, having regard to the fact, that under unfavourable conditions the short circuit current can be unsymmetrical and reach a momentary value nearly double the momentary value of the symmetrical current, we obtain a theoretical maximum value for the total hoop stress in the winding reaching nearly 30 tons. The total area of copper in the winding, which is subjected to a tensile stress of this amount is 16,200 mm². The mean tensile stress in the copper is therefore about 1.9 kg/mm². This value is not terribly high but can be carried by the copper, even if we assume that the turn nearest the interspace is subjected to a stress about double as great. Conditions are in general less favourable the larger the transformer. At present however there is no fear of such transformer sizes coming in question, where the hoop stresses just investigated are so great that the windings themselves are not able to take care of them. It is necessary to stay the inner winding effectively against the core, since a transformer winding, on account of its construction, can easily withstand tensile stresses but not compressive stresses. (Cf. the case of a thin walled tube under inner and outer pressure).

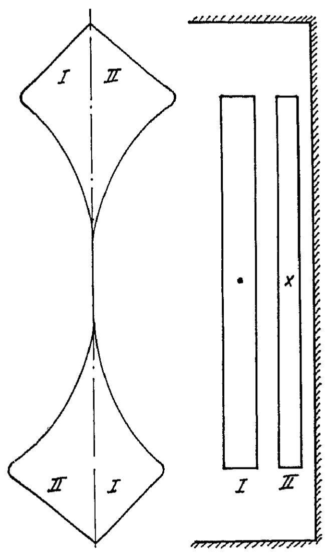


Fig. 5.

We have so far only referred to mechanical stresses produced by the axially propagated leakage flux. The radial components of the flux through the windings (fig. 2) must however give rise to stresses in the axial direction, which try to press the windings together about the middle. With a symmetrical arrangement of the windings these compressive stresses do not give rise to any resultant in the windings regarded as a whole. No axial stresses are accordingly thrown on the coil clamping devices at the ends of the windings. The oppositely directed stresses clearly give rise to an axial pressure in the winding, which is greatest at the middle of the winding and zero at its ends. The stresses over the winding vary approximately as shown in fig. 5. The curve in this figure is based on direct measurement of the radial flux components on a test transformer. The pressure in a certain part of the winding is clearly obtained

as the integral of the mechanical stresses from one of the ends of the winding to the part considered. For calculation of the strength of the inner axial pressure knowledge of the radial flux components of the leakage flux is required. Taking into account the action of the iron core, and several other factors, these components can only be calculated with the greatest difficulty. An estimation of the magnitude of the axial pressure can be obtained in another way, although the stresses thus calculated are too great. We can imagine windings in accordance with fig. 6 divided in the middle and somewhat separated, to a distance x. We assume now that, with a small value of x in relation to the dimensions of the windings, the leakage flux still runs quite axially at the point of division. The reluctance to the leakage flux has accordingly increased in the proportion $\frac{h+x}{h}$ and the coefficient of self induction of the winding is accordingly reduced in inverse proportion. We now use a proposition in electrodynamics, which states that the mechanical work done by the electrodynamic stresses during a displacement of the circuits is equal to the increase in the magnetic energy on account of the displacement. Let L be the coefficient of self induction of the winding with $x = 0$ and $L_x = \frac{h}{h+x} \cdot L$ the corresponding coefficient with $x = x$. The increase in magnetic energy with an infinitesimally small alteration of x is

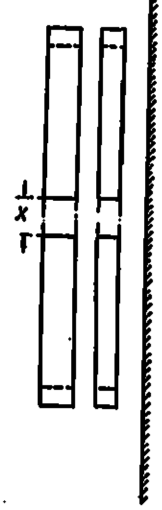


Fig. 6.

$$dW = \frac{i^2}{2}\frac{d\,L_x}{dx} \cdot dx$$

which according to the proposition just mentioned is equal to the work of the outer stresses Fdx, accordingly,

$$F = \frac{i^2}{2}\frac{d\,L_x}{dx}$$

with $x = 0$

$$\frac{d\,L_x}{dx} = -\frac{L}{h}$$

and therefore

$$F = -\frac{i^2}{2} \cdot \frac{L}{h}$$

The minus sign indicates that F acts in the direction opposed to decreasing x and accordingly is a compressive stress. The coefficient of self induction can easily be calculated from the dimensions of the winding or from the commonly given particulars regarding the reactance voltage. If the reactance voltage is e_k %, then

$$\omega L i = \frac{e_k}{100} \cdot e$$

where e is the maximum value of the phase voltage and

$$F = \frac{e_k}{100\,\omega} \cdot \frac{e\,i}{2\,h} \cdot 10.2 \text{ kg.}$$

In the transformer before considered e_k is 6 %, ei per phase $\frac{2 \cdot 2{,}500}{3} \cdot 10^3$ VA and the periodicity 50. With normal current strength 14.75 kg is obtained for the two windings combined. With short circuit on full voltage the maximum stress under unfavourable conditions in accordance with the foregoing can reach nearly 1,115 times this value, or 16.4 tons. Assuming this stress divides equally between both windings we thus obtain for each 8.2 tons. On account of the action of the iron core the compressive stresses are however increased somewhat on the inner winding and decreased on the outer. The magnitude of the compressive stress in the example considered can therefore be put at about 10 tons.

We have so far exclusively imagined windings fully symmetrically placed along the core and of equal height. If one winding is displaced relatively to the other in accordance with fig. 8 a it is clear, that the currents in the two windings give rise to stress components in the axial direction, which endeavour to further increase the want of symmetry, (since currents in opposite directions repel one another). The stresses arising in the axial direction on account of dissymetry are accordingly transferred direct to the end supports and clamping devices of the windings. As these supports must be made of insulating material and, with higher voltages, of considerable height, it is of importance to reduce the stresses transferred to them from the windings to the greatest possible extent.

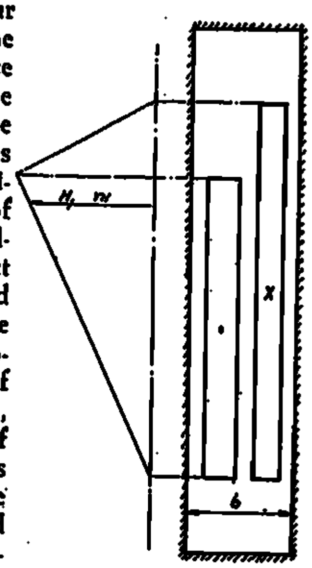


Fig. 7.

Looking now at figs. 8 b and 8 c both windings are symmetrically placed along the core but are of different height. Can axial stresses here be transferred to the end clamps? The

windings regarded as a whole are each clearly not subjected to any resultant axial stresses. As the windings cannot withstand any tensile stress in the axial direction, it is however possible, that equal and oppositely directed axial stresses can exist in the two halves of the windings, which are directly transferred to the end clamps.

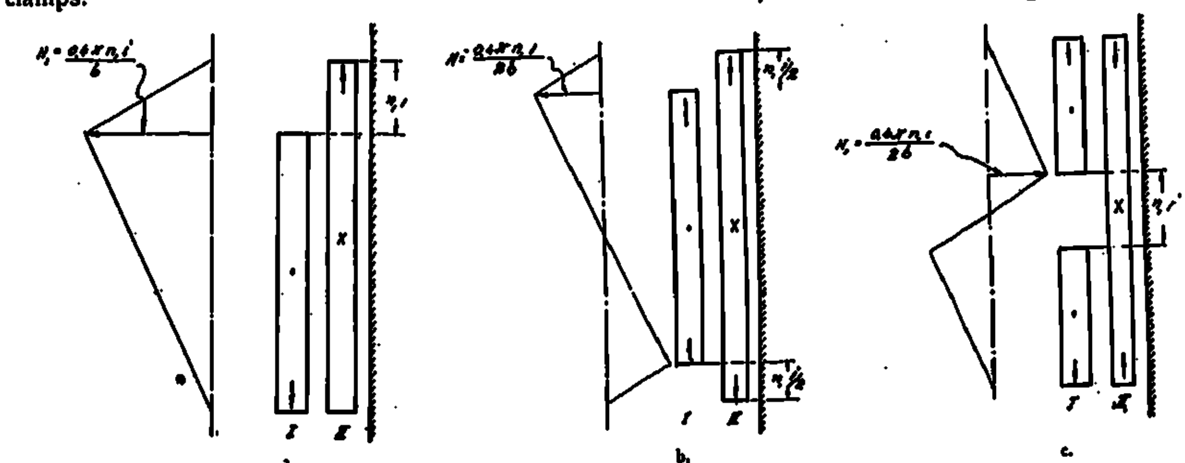


Fig. 8.

A study of the resulting amp. turn diagram for the two windings now makes it easily possible to judge the direction of the axial stresses, which occur with windings which do not cover one another. These resulting amp. turn diagrams are also shown in figs. 8 a, b and c. If the windings were placed in a closed slot, fig. 7, in a large iron mass the resulting amp. turns would produce a radial field practically in full agreement with the amp. turn diagram. Actually the conditions are qualitatively the same if quantitatively they are different. We can assume however, that even under actual conditions we could reckon with such a slot of breadth b. The fluxes set up would then be proportional to the resulting amp. turns shown in the figures. The figures show at once, that in fig. 8 a winding I is pulled downwards and II upwards; in 8 b I is compressed about the middle, while II is stretched outwards; in fig. 8 c the stresses are opposite to those in 8 b.

The magnitude of the axial stresses is obtained easily, if we remember, that the mean value of the field strength is equal to half the maximum value.

In fig. 8 a accordingly the axial stress is

$$\pi\, D\, \frac{0.4\, \pi\, n_1\, i}{2\, b} \cdot n\, i \cdot 1.02 \cdot 10^{-7} \text{ kg},$$

where D is the mean diameter of the windings, $n_1\, i$ the max. resulting amp. turns obtained from the amp. turn diagram; in all three cases the total number of amp. turns not covered is denoted by $n_1\, i$. In figs. 8 b and c the corresponding stresses, now acting on only half of the windings, are

$$\pi\, D\, \frac{0.4\, \pi\, n_1\, i}{2 \cdot 2\, b} \cdot \frac{n\, i}{2} \cdot 1.02 \cdot 10^{-7} \text{ kg}.$$

It is easy to see, that the magnitude of the axial stresses calculated in the way now indicated is proportional to the area of the amp. turn triangles. In cases where the diagram breaks up into several triangles, as e.g. in figs. 8 b and c, the maximum stress is proportional to the largest triangle. The stresses in figs. 8 b and c are accordingly only a quarter of the stresses in fig. 8 a.

For practical calculations we must fix the equivalent slot width b (fig. 7). By comparison with more exact methods of calculation, in simpler cases, and from measurements carried out, it is found that b can be put approximately equal to 2.5 times the width of the winding itself, inclusive of the interspace between the windings. This value naturally gives only quite approximate results but these are always on the safe side.

On the assumption that the transformer in the foregoing example had unsymmetrically placed windings (e.g. by disconnecting part of the windings for voltage regulation) corresponding to 5 % of the total number of amp. turns 28,000, an axial stress would be obtained in normal working with b = 27 cm and D_m 51 cm

$$A = \pi \cdot 51 \cdot 0.4\, \pi \cdot \frac{5}{100} \cdot \frac{1}{2 \cdot 27} \cdot (\sqrt{2} \cdot 28{,}000)^2 \cdot$$
$$\cdot\, 1.02 \cdot 10^{-7} = 30 \text{ kg}.$$

On short circuit under theoretically unfavourable conditions this stress is increased 1,115 times, which gives a maximum axial stress per

winding of not less than 33.5 tons. With the arrangement according to figs. 8 b and c the stress would be only a quarter of this.

By use of the resulting amp. turn diagram for calculating of axial stresses we obtain, with symmetrically placed windings, fully covering each other, no stresses. We have however already seen before that such are actually to be found. Superposed upon the axial stresses calculated from the amp. turn diagram clearly therefore there are axial compressive stresses corresponding to those existing with the symmetrical arrangement. With windings arranged according to figs. 8 b and c these "normal" axial stresses tend to decrease the stresses, which are transferred to the winding clamps, but instead of this they increase the internal pressure in the windings arranged for compression only. With the arrangement in fig. 8 a the pressure against the end clamps will be correctly estimated, while the internal pressure in the windings is still too small. The calculation of the distribution of axial stress along the winding is very difficult and is also of small interest, provided that the maximum stress arising *i. e.* the integral of the stresses along the winding is fairly correctly arrived at. The short circuit stresses in the axial direction, as calculated from the amp. turn diagram, are besides very considerably reduced on short circuit by saturation both of constructional parts such as tank and core clamps etc., as well as, under certain conditions, the core itself. If the pressure against the winding end clamps is calculated from the amp. turns diagram we obtain a value which lies on the safe side, which is just as well having regard to the fact that by possible shrinking together of the windings any lack of symmetry may be increased. The maximum internal pressure in the windings can be estimated for any case by superposition of the two kinds of axial stresses. With windings arranged on sound principles it is relatively easy to obtain an arrangement suitably strong to resist the axial pressure, so that the possibility of a correct estimate of such internal compressive stresses is not so important. The greatest advantage of this simplified method lies also, not in the exact calculation of short circuit stresses, but in the possibility of determining from the diagram how the stresses can be reduced in the easiest way. In this connection it may be pointed out, that with an unsymmetrical arrangement of windings, the radial flux which arises often evidences itself in an unpleasant manner by eddy current losses in the tank, core clamping flanges, and sometimes in the windings themselves. The presence of eddy current losses in the tank is easily noted by the occurrence of hot bands in the places where the radial field causes the greatest flux density in the tank in the axial direction. Regard for eddy current losses accordingly supplies a further reason for reducing want of symmetry between the windings in the best manner.

From the foregoing it has been shown that under short circuit conditions particularly large mechanical stresses occur both in the radial and in the axial directions in concentrically arranged windings in a core transformer. The stresses are, in respect to their effect, partly inward, which are taken up by the windings themselves or are transferred in the radial direction to the core and partly outward which are transferred to the winding end clamps. Stresses acting outwards arise only if the primary and secondary windings of the transformer are unsymmetrical in respect to each other or do not fully cover each other along the length of the core. In a well constructed transformer the windings must be built up so that they can, without deformation of copper and insulating material, withstand the inward acting stresses. This is achieved by a suitable choice of conductor dimensions, the use of insulation interleaved between turns, the employment of mechanically resistant material, such as presspahn or bakelite, and impregnation and baking of coils. The outward stresses which are transferred direct to the winding end supports must, on account of the difficulty of obtaining, at the same time, good insulation and great mechanical strength for these supporting clamps, as far as possible be limited e. g. by getting rid of want of symmetry between the windings or a suitable distribution of the unpreventable lack of symmetry caused by the tappings and reconnection of windings desired. Winding supports and clamps should be dimensioned particularly strong even with symmetrical windings because of the small dissymetries which occur in time due to shrinkage. Take up devices, if possible automatic in action, should be used to prevent the windings working loose and moving up and down under the action of the mechanical stresses.

THE PROPER SELECTION OF SIZE FOR MACHINES USING ELECTRIC POWER.

To the question "How large a motor or transformer should be purchased for a given purpose?", the reply from a practical point of view may immediately be given, "The smallest which will be satisfactory for the duty under consideration". That the motor must be large enough for the job in hand is perfectly clear, but it is by no means so easy to state definitely what size is

Transformers with small no-load losses.

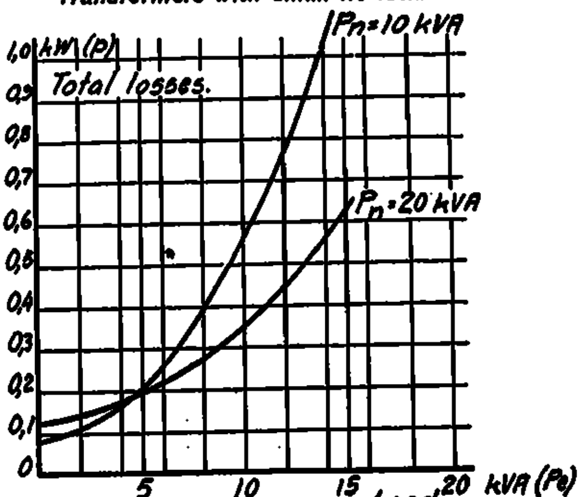


Fig. 1.

necessary to ensure this, as different conditions may cause wide variation in power requirements, and in addition a future increase in the load must usually be reckoned with. Practical conditions thus make it advisible to choose the motor as much on the safe side as the above-named conditions, acting alone or in conjunction, may make desirable. In the same connection it is important to see that the motor will be capable of dealing with the overloads which may be expected to occur, so that it does not pull up and give rise to a cessation of work every time an overload of such magnitude takes place. A motor which never causes work to be held up in this way is undoubtedly of greater value.

When careful attention has been given to this "safe side" in determining the size of a motor (or transformer), the problem is next, to choose the smallest and cheapest motor possible, which can be obtained from the manufacturing firms.

The problem is, however, not quite so simple as the above. Competition has by degrees forced manufacturers to supply standard motors and transformers having such characteristics that the smallest is often far from being the cheapest in service, and this fact brings us to the economic side of the question.

In order to meet the demand for low no-load power consumption, particularly in rural electrification work, transformers with exceedingly small "no-load losses" have been designed and placed on the market. In these transformers less attention has been given to the magnitude of the losses occurring on load, and the greatest amount of effort has been expended in producing transformers at a low price. It is true that this is well justified under the special conditions which have given rise to the production of such transformers, but it does not do to forget that other cases must be approached from a different point of view.

To make this point clear we show in fig. 1 curves of total losses in two transformers with small no-load losses, one for a nominal output (rating plate) of 10 kVA (P_n), and the other of 20 kVA — generally as they are given in the manufacturers catalogues.

Up to a load of 4.3 kVA the smaller transformer has lower losses and consequently a higher efficiency, but above this the large has lower losses and higher efficiency. With a load of 10 kVA, that is to say at the normal output of the smaller transformer, the losses of this are not less than 0.21 kW (60 %) greater than the losses of the larger transformer, and on overload the difference is still more marked. With, for example, a connected time of 3,000 hours per year, half the time on no load and half the time on a load of 10 kVA, 969 kWh are expended due to losses in the smaller transformer, while in the larger transformer the figure

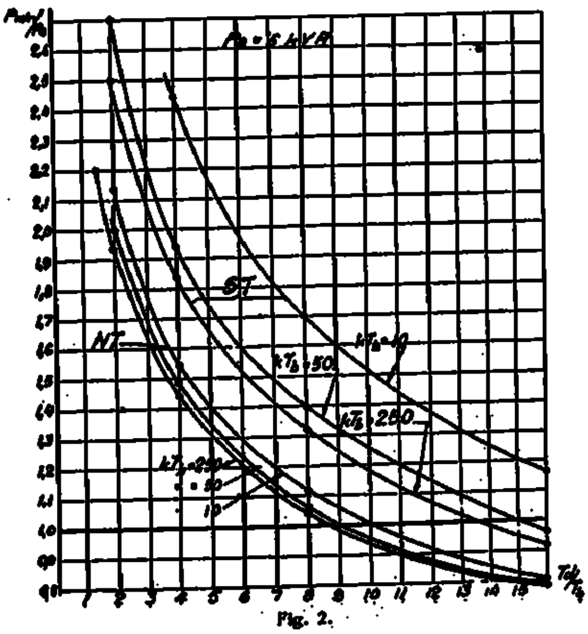


Fig. 2.

s only 715 kWh. The difference, 254 kWh, may easily outweigh the higher first cost of the larger transformer if the price of power per kWh is fairly high. This is accentuated by the fact that the amortisation time of the larger transformer may certainly be assumed to be longer (and the amortisation percentage lower).

In this case a 10 kVA transformer with "normal" no-load losses is not found to be more suitable, since the wasted energy during the year reaches 1,080 kWh. A similar transformer of 20 kVA would require 917 kWh per year in losses.

With induction motors conditions are somewhat similar, although in this case we have to take note of the effect of power factor. Strictly speaking, this effect should also be noted as regards transformers, but as it is then quite inconsiderable we have not considered it necessary to refer to it.

Our opinion however, is that the standardisation of small mass production transformers and three-phase motors makes it necessary to select the size of such plant with great care, paying attention to their characteristics, running conditions and to the cost of power in order to obtain the best possible results in working. As an indication as to how this selection should be made, we give below a simple analysis of the problem, showing the results in a number of tables and curves. The constants for characteristics, cost etc. are approximately those we have obtained from catalogues and descriptions which are available covering transformers and motors on the market. Our intention is, accordingly, not to give any direct instructions for design, but simply to urge the purchaser to make use in the most economical way of the manufactures which are at present available.

1. *Transformers.*

For a transformer the losses (p, kW) with load of P_e kVA are approximately

$$p = a + b\,P_e^2 \text{ kW}$$

where a and b are constants for a certain transformer depending on its size, *i.e.* its kVA output

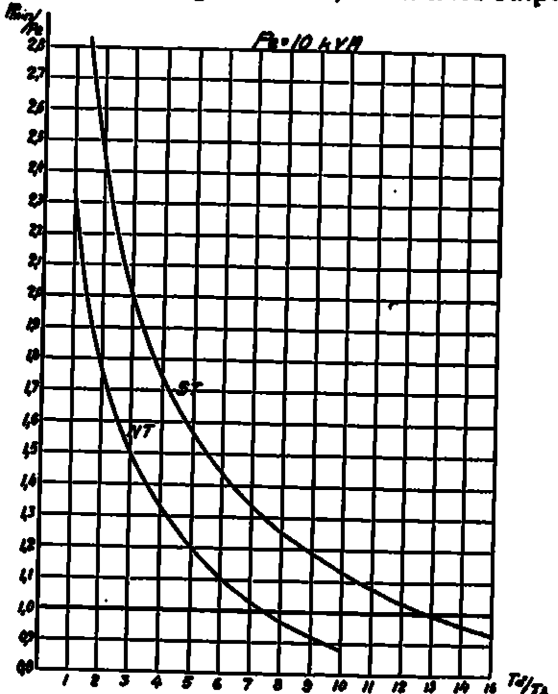


Fig. 4.

as stamped on the rating plate (P_n). The first term corresponds to the iron (no-load) losses, and the second to the copper (load) losses. The constants a and b can accordingly be expressed:

$$\begin{cases} a = c + d\,P_n \\ b = \dfrac{e}{P_n^m} \end{cases}$$

We thus have

$$p = c + d\,P_n + \frac{e}{P_n^m} \cdot P_e^2 \text{kW}$$

If T_d is the working time in hours per year (= the total time connected to the supply) and T_b the time also in hours per year during which the transformer is loaded with P_e kVA, then the power losses

$$w = T_d(c + d\,P_n) + T_b \cdot \frac{e}{P_n^m} \cdot P_e^2 \text{ kWh per year.}$$

If the cost of power is k shillings per kWh, the cost of the total losses is

$$k \cdot w \text{ s. per year.}$$

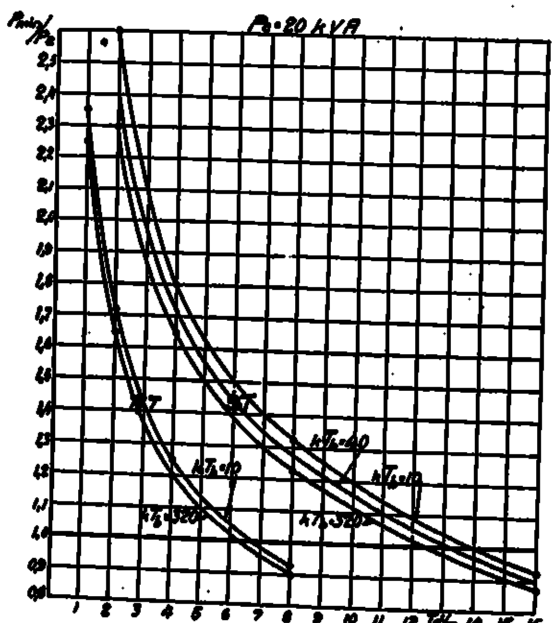


Fig. 3.

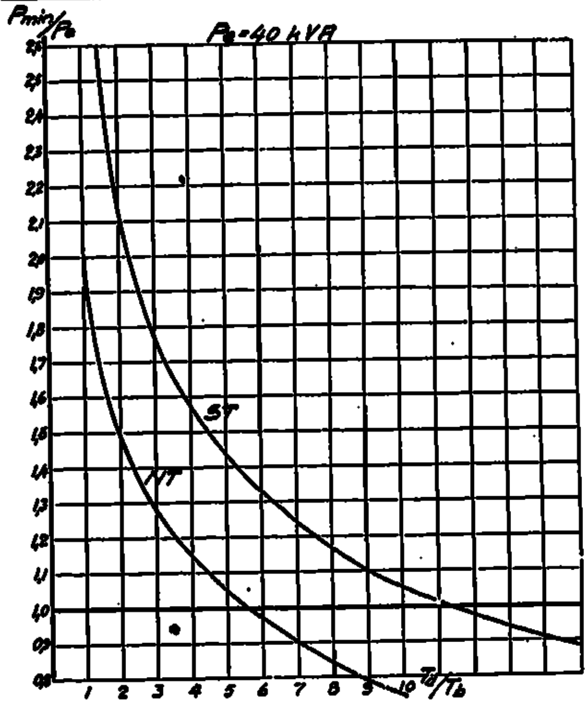


Fig. 5.

If the first cost of the transformer is K s. we can put

$$K = g + h\sqrt{P_n}$$

If the amortisation and capital charges are put at $A \cdot 100$ %, then $A \cdot K$ = the outlay per year for these charges. Having regard to the fact that a transformer is depreciated less when loaded to a small extent, we may lastly put

$$A = f\sqrt{\frac{P_e}{P_n}}$$

in which $f \cdot 100$ is the "normal" outlay per year in % for capital charges and depreciation (upkeep and repairs respectively). We have assumed below that $f = 0.10$.

The total running cost is accordingly

$$D = wk + AK \text{ shillings per year}$$

We now have to find a value of P_n which makes D a minimum, or to solve the equation:

$$\frac{dD}{dP_n} = 0$$

	NT	ST
c	0.055	0.045
d	0.0078	0.0041
e	0.085	0.06
f	0.10	0.10
g	10	30
h	107	132
m	1.27	1.1

In the table at the side we give the values of the constants which have been found to correspond to low tension self-cooled oil immersed transformers of from 5 to 50 kVA at 50 cycles, partly with "normal" (NT), and partly with "small" no-load losses (ST). Substituting these values in the last equation above, we obtain the value of P_n, *i.e.* the nominal size of the transformer which gives the lowest running cost ($P_{min.}$).

1. For transformers with normal no-load losses from the equation

$$\frac{P_e^2}{P_{min}^{2.37}} = 0.0723\frac{T_d}{T_b}\left(-\frac{4.63}{kT_b}\sqrt{\frac{P_e}{P_{min}^3}}\right)$$

2. For transformers with small no-load losses from the equation

$$\frac{P_e^2}{P_{min}^{2.1}} = 0.062\frac{T_d}{T_b}\left(-\frac{22.8}{kT_b}\sqrt{\frac{P_e}{P_{min}^3}}\right)$$

The two last terms, [in ( )], can however be neglected without great inaccuracy, at least as a first approximation, and then it is easy to find the numerical value of P_{min}.

From these two expressions it will first of all be seen that the best value P_n for a certain value P_e depends chiefly on the relation T_d/T_b and only to a less extent on the product kT_b. This has further a less effect for NT than ST transformers, and is less the greater the output (P_e) which the transformer is to develop.

In fig. 2 curves are drawn which show this relation for P_e = 5 kVA, and in fig. 3 for P_e = 20 kVA. In figs. 4 and 5 will be found curves for 10 and 40 kVA, although only calculated for a large value of kT_b and accordingly corresponding to the lower curves in figs. 2 and 3.

These results are shown combined in figs. 6 and 7, and some of the most important points arising out of them are given below:

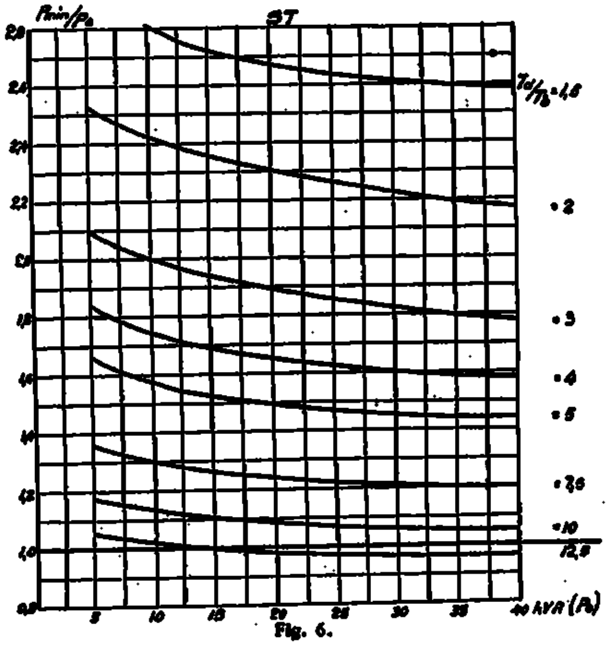


Fig. 6.

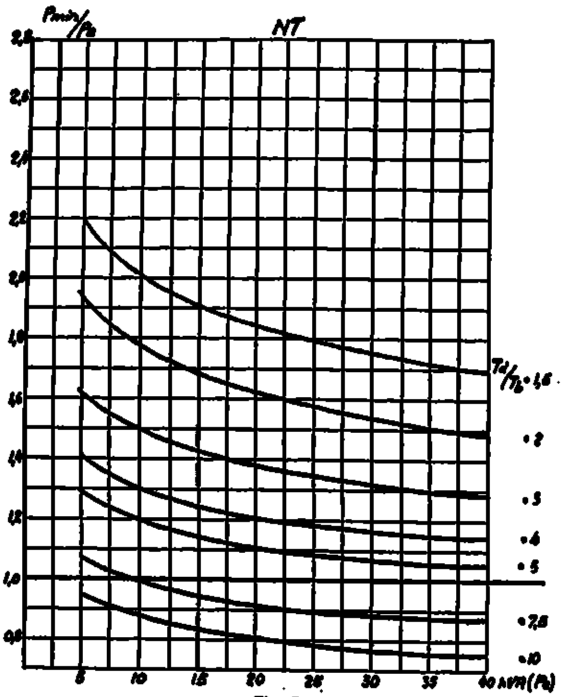


Fig. 7.

A transformer with normal no load losses (fig. 7) is only suitable for running at the output stamped on the rating plate when it is loaded for about one-sixth of the actual time it is connected. If it is loaded to a greater extent a larger transformer should be used. If, for example 15 kVA (P_e) is required, and the load is on during half the working time (*i.e.* $T_d/T_b = 2$), then $P_{min}/P_e = 1.68$ and it follows that the most suitable size of transformer is $P_n = 1.68 \cdot 15 = 25$ kVA.

When the continuous load occurs during less than one-sixth of the total running time it will be most suitable to use a transformer for an output less than the figure actually required. From other considerations, (heating, voltage drop etc.) this cannot often be done, so that either the transformer must be chosen with $P_n = P_e$ or else an investigation must be made to show how a transformer with extra small no load losses would meet the case.

The curves for such transformers are given in fig. 6, and it follows from these that they are most suitable where the load factor is only about $^1/_{12}$ of the total running time, and also that a low value of T_d/T_b may give rise to greater enlargement than would be the case with *NT* transformers. At the same time the curves show no mutual comparison between the two types as regards economy and running cost, but in each separate case a comparison must be made between the two best transformers of each type which can be obtained.

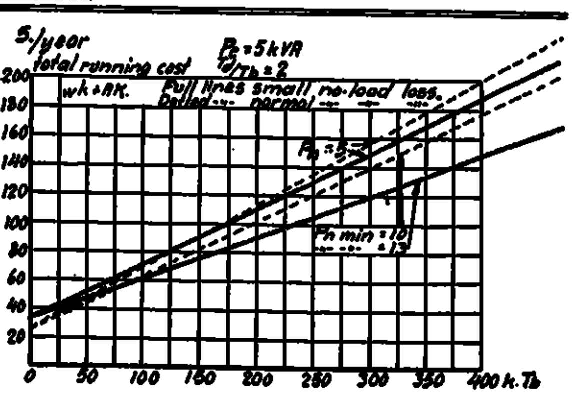


Fig. 8.

In figs. 8—11 we have further estimated the total annual cost $(wk + AK)$ for several sizes within the range under consideration (5—50 kVA) as a function of the product kT_b, which is of importance in this respect. The calculation has been made for $T_d/T_b = 2$ part for a transformer of which the nominal output is equal to the actual load ($P_n = P_e$), part for the transformer, which in accordance with the above mentioned gives the lowest annual cost ($P_n = P_{min}$).

If, for example, we require 20 kVA and $kT_b = 200$, we obtain, using a 20 kVA transformer with small no load losses, a total annual cost of 290 s.; a 20 kVA transformer with normal no load losses gives an annual cost of 285 s. The transformer with normal no load losses which gives the lowest possible annual cost is of 33 kVA, and the cost comes to 250 s. The cheapest possible working is obtained with a transformer with small no load losses and of 46 kVA, working in this case costing 225 s. per year. Of course this does not include the cost of power actually utilised, which is the same in all cases. The greatest possible gain which we can obtain in this case by suitable choice of size is accordingly 65 s. per year.

It is hardly necessary to point out that the gain obtainable is greater the higher the cost for energy, and the longer the time the load is on for a given relation T_d/T_b. In the same way that the gain for a certain kT_b is greater,

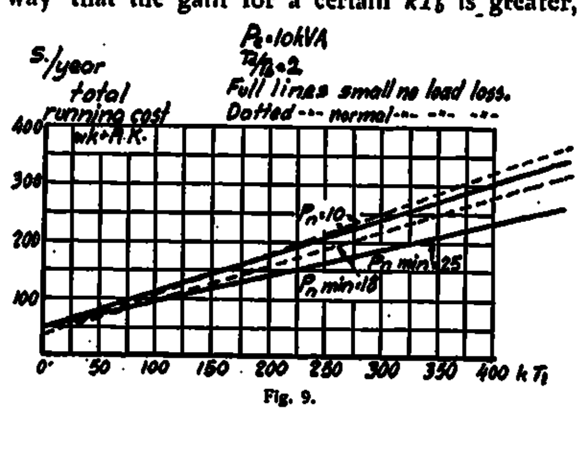


Fig. 9.

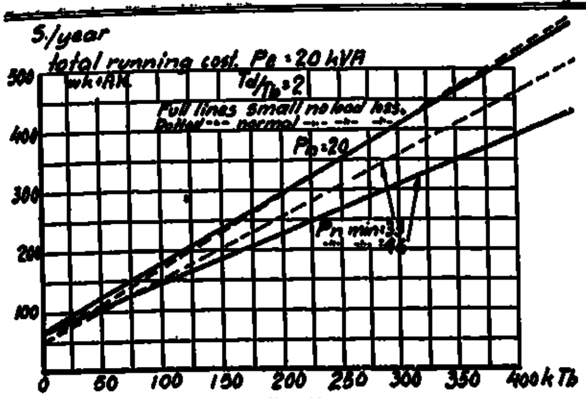


Fig. 10.

so T_d becomes less and approaches T_b. Among other things which can be clearly seen is that a transformer which is connected and loaded for times coinciding exactly with the running conditions of a practically fully loaded motor, requires to be of entirely different size from a transformer intended for rural supply which is connected during the whole year, but only loaded during an exceedingly short part of the time.

The results which we have reached as a result of the above treatment should be regarded more in the nature of an example than as a fixed general rule, and a few remarks may well be added in this respect. First of all, it might be objected that an increased capital outlay is in itself such a disadvantage that these means could never be used in order to obtain more economical working. To this point of view the only answer is that in this case all calculations of an economic character become useless. On the other hand, it is of course possible to go too far in this direction. Since the solutions of such (minimum) problems do not give a sharply defined result, and we have a good margin on opposite sides of the point which is theoretically the "best", and within which results are not worse to any appreciable extent, it is advisable to keep a little below this "best" with regard, among other things, to the capital outlay, which accordingly, and rightly, can only influence the result to a small degree.

It may also be objected that amortisation is made to appear very dependent on the proper selection of the size of the transformer. If, however, we think of the great extent to which a high working temperature affects the life of the important insulating materials used in transformers, e.g. cotton and oil, and if we give proper consideration to the advantages as regards motors and lamps obtained by adopting a reasonable voltage drop, and lastly the practical advantage of having a transformer able to withstand the overloads which occur or to meet possible extensions without requiring to be changed, it will probably be agreed that the amortisation is affected by proper choice of size to a very great extent. In addition it is possible to see a reason in this circumstance for not limiting the choice of the transformer actually to that size which is calculated to be theoretically the best.

2. *Motors.*

As regards three-phase induction motors we can proceed in much the same manner as for transformers. It is found, however, that the buying price can be better stated in an expression of the form $K = g + hP_n^{0.78}$ s. where P_n is the power given out in kW.

Making use of the normal amortisation factor $(f) = 0.12$, we find that the constants, at the present time, can be given values approximately as given in the table below, as regards low tension 4-pole motors of 50 cycles of the slipring type between 5 and 75 kW.

c	d	e	f	g	h	m
0.12	0.025	0.20	0.12	130	70	1.3

By substituting these constants and remembering that P_e denotes the actual load given by the machine, and P_n the output in kW in accordance with the rating plate, we obtain the size of the motor, P_{min} which gives the least running cost from the equation:

$$\frac{P_e^2}{P_{min}^{2.4}} = 0.1 \cdot T_d/T_b + \frac{1}{kT_b}\left(\frac{7.1\sqrt{P_e}}{P_{min}^{0.78}} - \frac{30.4\sqrt{P_e}}{P_{min}^{1.8}}\right)$$

By successive approximation we can calculate and trace curves of the same kind as shown previously for transformers. At the same time, regarding motors, we must take note of a circumstance which was neglected when dealing with transformers, namely the effect which the size of the motor exercises on the power factor ($\cos\varphi$). The reactive power (and energy) which the motor takes always represents a charge, even if this is not always made to the consumer.

This first question is accordingly to determine how the inductive power is related to the

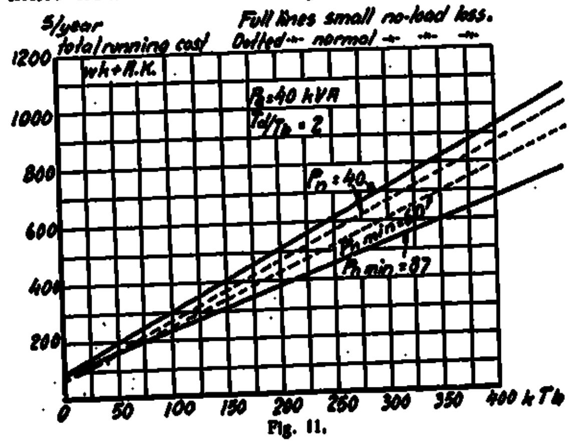


Fig. 11.

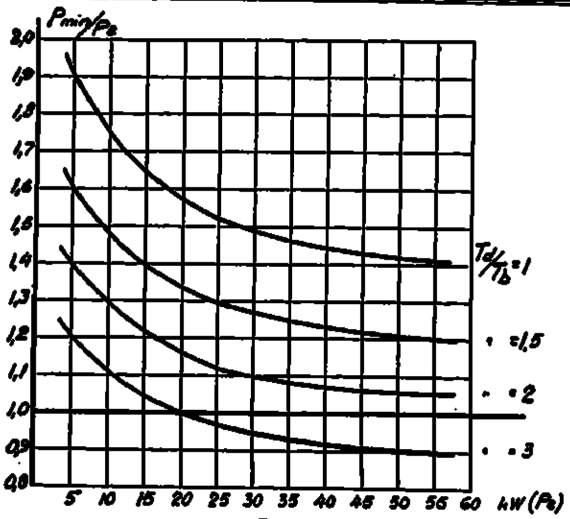


Fig. 12.

size of the motor and to the load on it. By analysis of the Heyland diagram, for example, we find that the reactive power, P_r, can be approximately expressed as

$$P_r = a' + b' \, P_e^2 \text{ rkW}$$

$$a' = c' + d' \, P_n$$

and

$$b' = \frac{e'}{P_n^{m'}}$$

where P_e and P_n have the meaning given above. We accordingly obtain the reactive energy used, which is:

$$w_r = T_d (c' + d' \, P_n) + T_b \frac{e'}{P_n^{m'}} \cdot P_e^2 \text{ rkWh per year.}$$

(*Note.* rkWh = reactive kWh or re-kWh).

If the price for reactive energy is k_r s. per reactive kWh, then the cost $= k_r w_r$ s. per year. In this way the problem can now be solved if we know the value of these constants.

On investigation of the same series of motors as above in this respect, the following values have been found.

c'	d'	e'	m'
1.0	0.36	0.20	1.0

The total running cost is accordingly:
$D = kw + k_r w_r + AK$ s. per year and the value of P_n which gives the lowest running cost (P_{min}) is obtained from the equation

$$\frac{dD}{dP_n} = 0$$

On continuing this treatment, however, a difficulty is met with, as it is not possible to assume any definite price for reactive energy, or at least to arrive at a definite relation between these and the cost of power. The last can be determined with some degree of certainty if we think of all the reactive energy being absorbed on site by synchronous motors specially installed for the purpose. For a case on rather a large scale it has been found that we can put

$$k_r = \frac{1}{30} \cdot k$$

and in this formula other advantages of these synchronous motors have to some extent been included, particularly with regard to voltage regulation.

With a very little further approximation we can lastly obtain the size of motor which gives the lowest running cost, (P_{min}) from the equation.

$$\frac{P_e^2}{P_{min}^{2.8}} = 0.134 \cdot T_d/T_b + \frac{1}{k\,T_b}\left(\frac{6.7\sqrt{P_e}}{P_{min}^{0.78}} - \frac{28.5\sqrt{P_e}}{P_{min}^{1.8}}\right)$$

In this last expression we can also neglect the second term on the right hand side, and this with less error the larger kT_b. In this way we have calculated the value which is used as a basis for the curves in fig. 12. It follows from these that the motors of the series in question are most suitable for running with the output stamped on the rating plate in the case where the running time is from two to three times as long as the time during which they are loaded, somewhat different for larger and smaller motors. If the time during which the machine is loaded is relatively longer, a larger motor is required for a given output in order to obtain the most economical results.

In comparison with transformers we find that the enlarging conditions (P_{min}/P_e) is considerably reduced, depending of course among other things on the assumption which has been made as regards the reactive power of the motor and

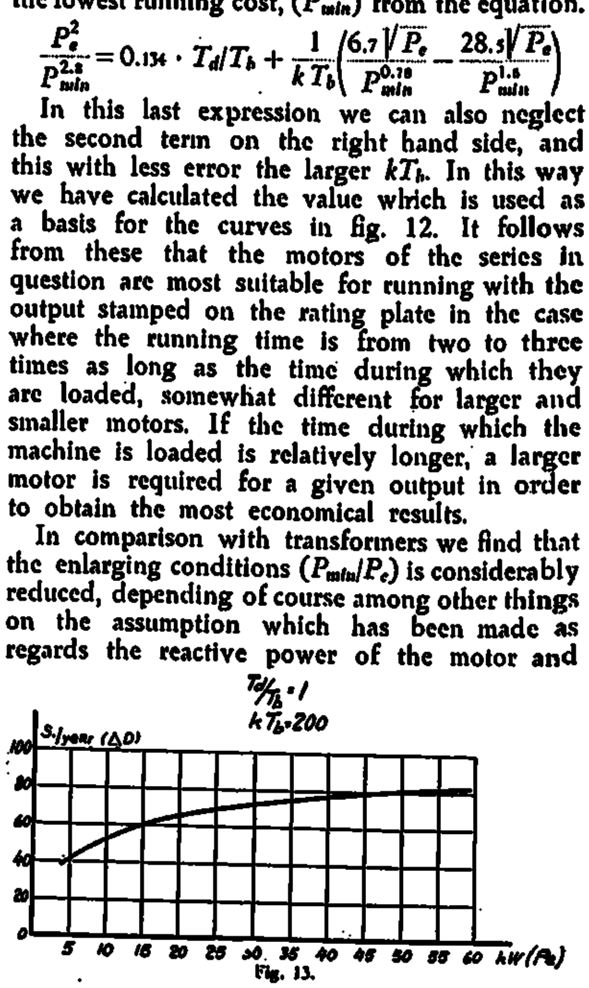


Fig. 13.

the cost of compensating for this. It would be possible to go considerably further with respect to economy if, we ordered a motor, not only of larger size, but at the same time designed for a higher voltage than that on which it was intended to be used. Here, however, we begin to touch on constructional questions which it is not intended to deal with in this connection.

In fig. 13 we have lastly given as an example

the gain effected per year by selecting the motor in accordance with the upper curve in fig. 12, *i.e.* for the case where the motor runs fully loaded for the whole of the running time, and we have further assumed that this is so great that $kT_b = 200$.

If we require 15 kW (*i.e.* 20 h.p.) and purchase a motor of 24.5 kW (33 h.p.), this will cost 210 s. more but permits a decrease of 60 s. in the yearly running cost. This is an exceedingly good return for the additional capital outlay. Even if the example given above is a particularly favourable, case, an investigation of the relations with which we have dealt will make it clear that in many cases the most expensive plant is cheapest in the end.

FRONT PAGE.

One of the greatest advantages of the rotary converter is the high efficiency which is possible, and this type of machine has been increasingly employed during the last few years.

The illustration on the first page of the present number of the Journal shows one of the largest rotary converters in use in Sweden, and this machine was supplied by Asea to the Norrkoping Electricity Works in 1918. This is designed for an output of 1,500 kW and converts three-phase 50 cycles to continuous current at 460 volts. The photograph gives a good idea of the solid construction which has been adopted, particularly as regards the brush gear, a detail which to a great extent affects the dependability for which all Asea machines are noted.

ELECTRICALLY DRIVEN ROLLING MILLS.

Referring to Asea Journal Nos. 7—9 for July —September dealing with the electrical drive of rolling mills we have in this number included some photographs showing some typical installations for Swedish Mills. The upper view on page 170 shows a two-speed induction motor direct coupled to a tube rolling mill, started in September 1925. As the mill has no fly-wheel, the motor has to stand extremely large peak loads.

The lower view on the same page shows Asea three-phase induction motors of the mill type MR for auxiliary drive in rolling mills. Concerning the peculiar construction and solid design of these motors we think the picture on the right will give a good idea in this respect.

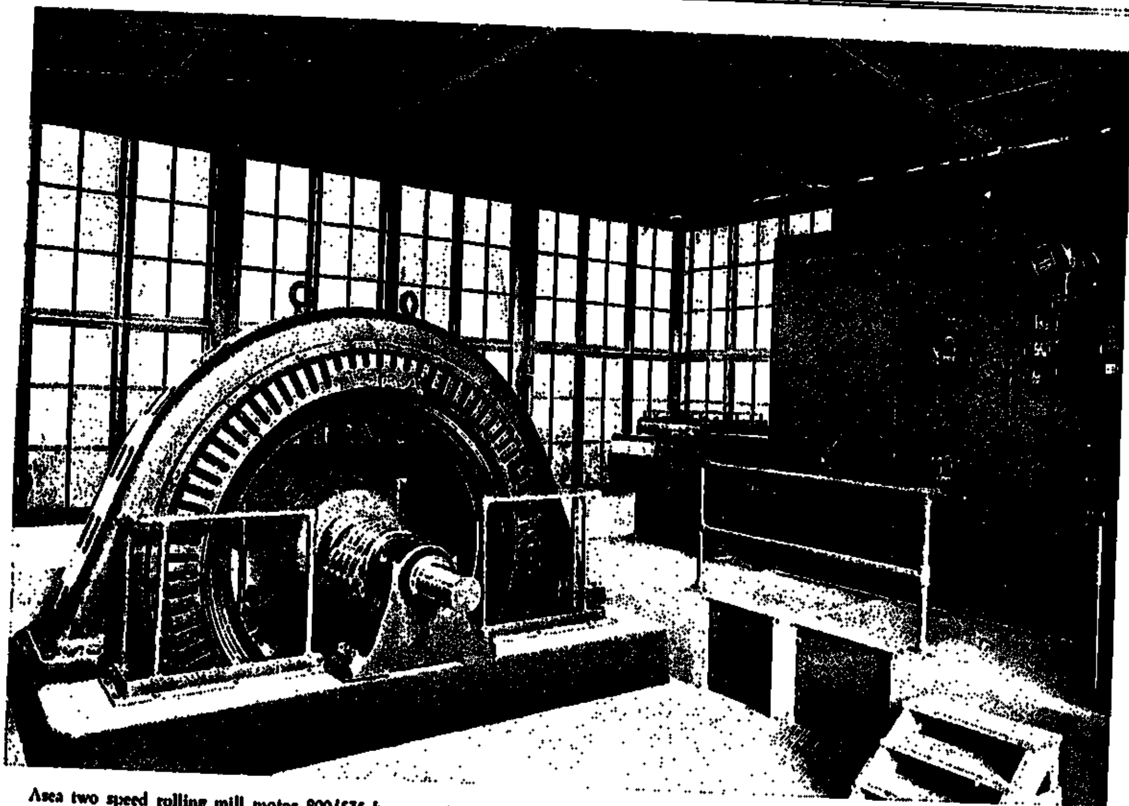
On page 171 the upper view shows a new Asea installation for a Swedish mill started in July 1925. The photograph shows the motor generator set with two DC generators, each supplying a DC rolling mill motor, the one rated for 600 h.p. continuous output and 1,200 h.p. max. output, within a speed range of 200—400 r.p.m., for an intermediary train, and the other rated 900 h.p. continuous output and 1,800 h.p. max. output, within a speed range of 180—425 r.p.m., for a finishing train. The driving motor of the motor generator set is a synchronous motor rated 1,910 kVA and a mechanical output of 1,670 h.p., 750 r.p.m., 50 cycles, with a leading power factor 0.7, acting as a phase advancer on the 500 volts AC supply. The speed of the rolling mill motors is adjustable in accordance with the Ward-Leonard control system.

On the left hand side of the photograph is the iron clad switchboard with control handles and instruments and some of the starters and field regulators.

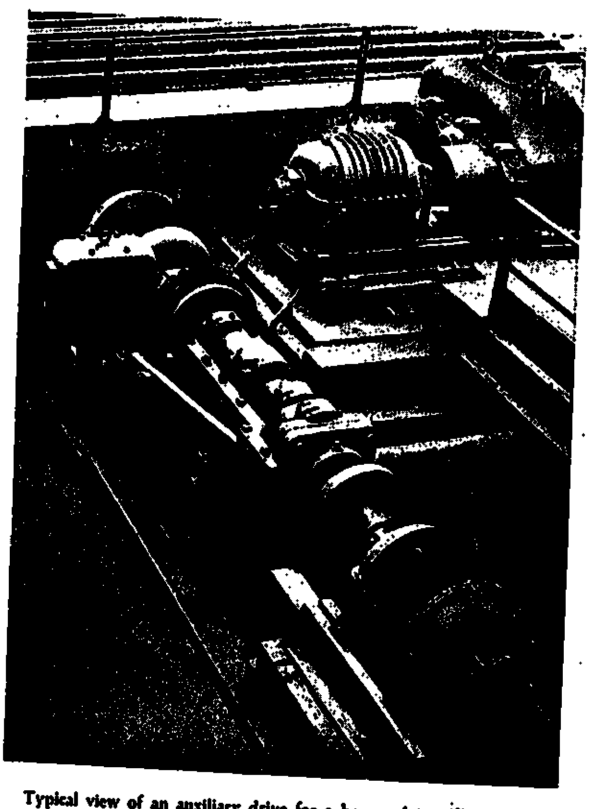
The lower view on page 171 shows some contactor panels in sheet iron housings mounted direct on the mill floor. These contactors manipulate the auxiliary drive in a cogging mill and are electrically operated by small master controllers. They work on the current limit principle, thus making the handling of the motor very simple and without risk even if in the hands of unskilled people.

As the work which the auxiliary motors have to deal with is largely acceleration and retardation the number of running positions of the controller can be reduced to a minimum and with motors of small and medium size, say up to about 30 h.p. only one running position is required and only contactors for reversing the motor are necessary.

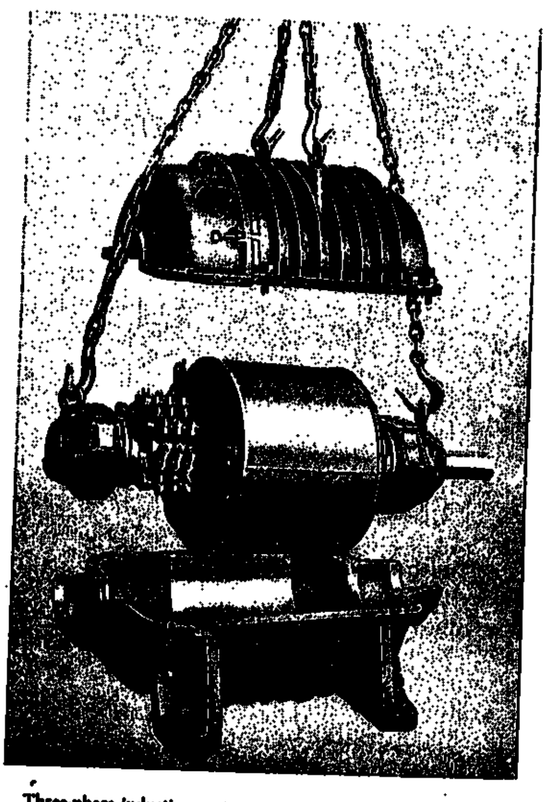
The above information together with the general description in Nos. 7—9 of Asea Journal illustrates in a decided manner that nothing concerning the electric main drive or the auxiliary drive of all kinds of rolling mills is unknown to Asea. Our experience during more than 40 years in this branch will be the best guarantee of suitable material and of the most solid design, fully corresponding to the requirements of hard rolling mill work.



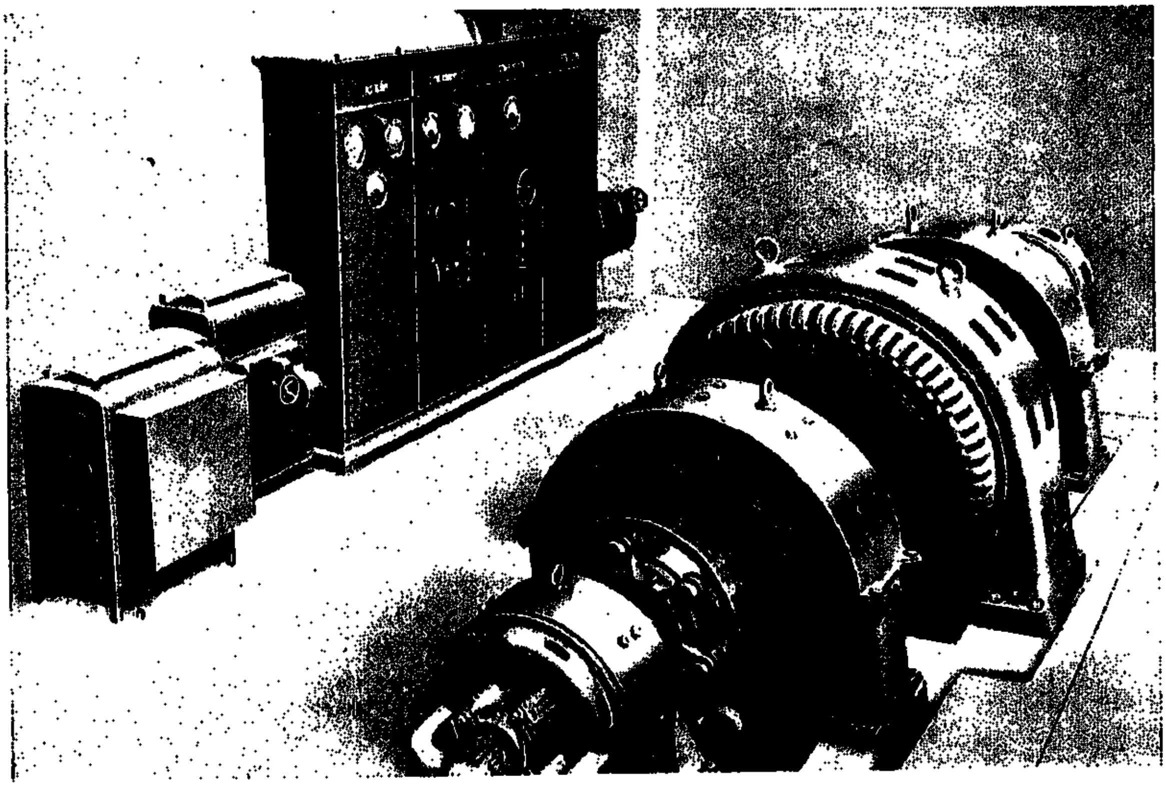
Asea two speed rolling mill motor 800/535 h.p., cont. output, three-phase 780/630 volts, 50 cycles, 240/160 r.p.m., for a tube mill.



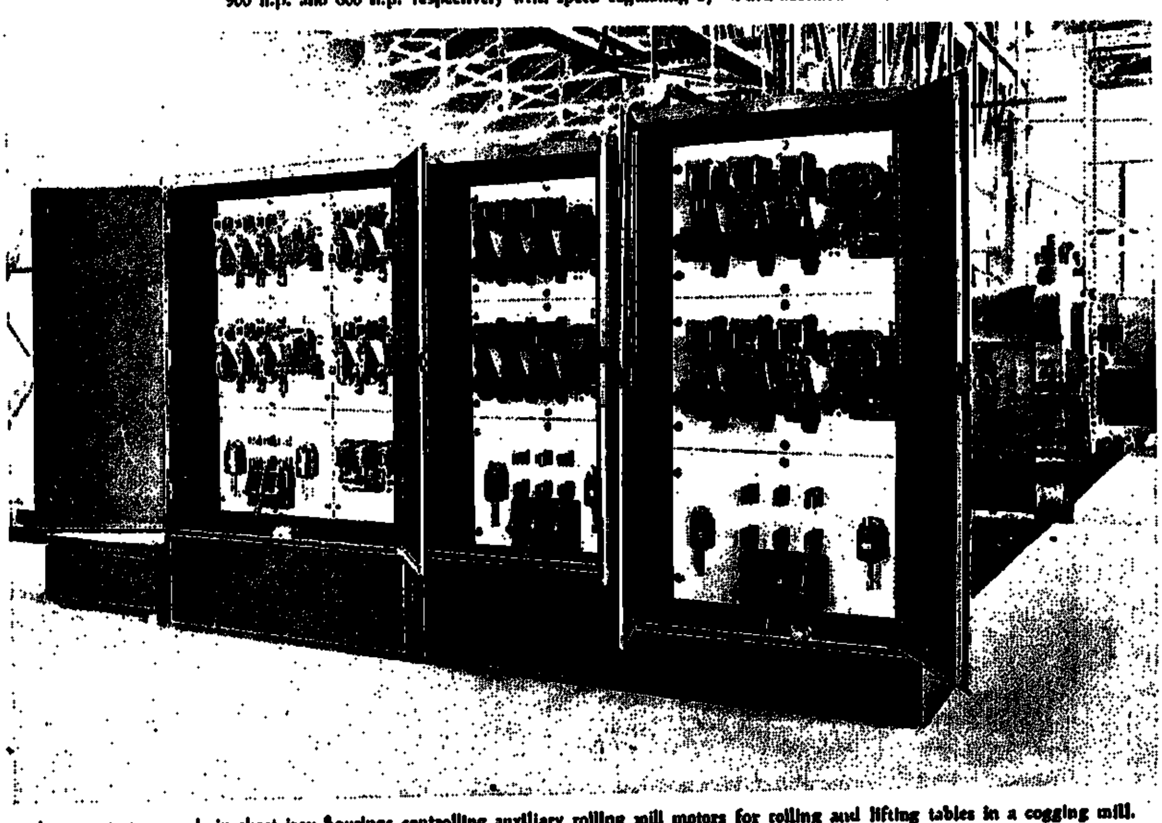
Typical view of an auxiliary drive for a heavy plate mill equipped by Asea. motors type MR.



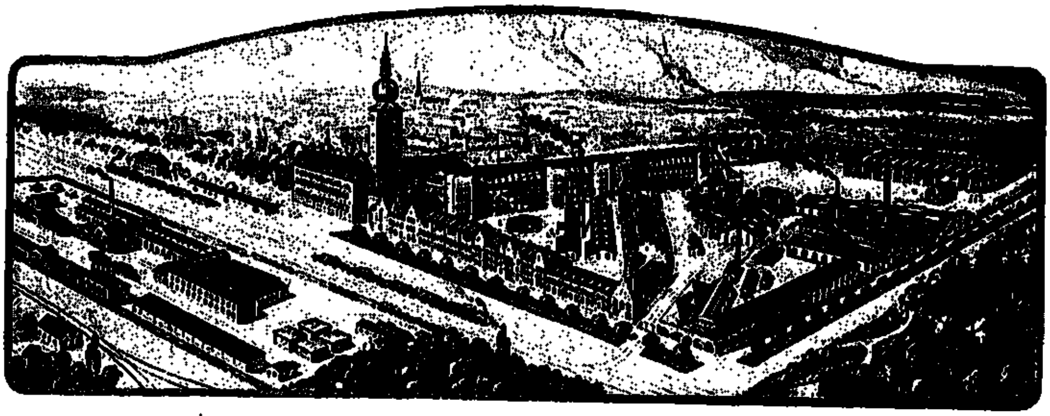
Three-phase induction motor type MR, one hour rating 15, 25, 30, 50, 75, and 100 h.p., for the auxiliary drive in rolling mills.



Asea motor generator set consisting of: 1 three-phase synchronous motor 1,910 kVA, 500 volts, 50 cycles, 750 r.p.m., 1 DC generator 710 kW cont. output, 1 DC generator 475 kW cont. output, 1 exciter, 1 starting motor, for driving two rolling mill DC motors 900 h.p. and 600 h.p. respectively with speed regulating by Ward-Leonard control.



Asea contactor panels in sheet iron housings controlling auxiliary rolling mill motors for rolling and lifting tables in a cogging mill.



Asea's head office and works in Vesteras, Sweden.

ALLMANNA SVENSKA ELEKTRISKA A.B.

Head office: VESTERAS, SWEDEN
Works: Vesteras and Ludvika
Telegrams: Asea, Vesteras

SWEDISH GENERAL ELECTRIC LTD

5, CHANCERY LANE, LONDON
Works: Fulbourne Rd., Walthamstow
Telegrams: Autosyncro, Fleet, London

FOREIGN REPRESENTATIVES:

ARGENTINA
Compañía Sudamericana SKF, Buenos Aires. Victoria 502.

AUSTRALIA
Unbehaun & Johnstone, Ltd., Perth, W. A. 383/387 Murray Street.
Unbehaun & Johnstone, Ltd., Adelaide, 98/100 Currie Street.
Thomas Bros. Pty. Ltd., Melbourne. 201/203 William Street.
Australectric, Ltd., Sydney, 97 Clarence Street.
Intercolonial Boring Co. Ltd., Brisbane, 418/424 Ann Street.

BELGIUM
Société Belge d'Electricité Asea, Bruxelles, 21 Rue Grétry.

BOLIVIA
Graham, Rowe & Co., Oruro, Alianza 581.

BRAZIL
Haupt & Co., Rio de Janeiro, Rua São Pedro 50
São Paulo, Rua da Boa Vista 46.
Porto Alegre, Rua 15 de Novembre 16.

CANADA
Swedish General Electric Ltd., Toronto 2, Ont., 107 Duke Street.

CHILE
Graham, Rowe & Co., Valparaiso, Cochrane 825.
Santiago, Bandera 267—275.
Antofagasta, San Martin 362.

CHINA
Henry J. Moysey, Shanghai, Peking Road 64.
Whittall & Company Ltd. Tientsin. 15 Victoria Terrace.

CUBA
Compañía SKF de Cuba, Habana, O'Reilly, No. 21.

DENMARK
Elektricitets Aktieselskabet Asea, Copenhagen K, Bredgade 45.

ESTHONIA
Elektrotechn. Büro Linke & Martinson. Reval, Kinga tän 10.

FINLAND
Allmänna Elektriska Aktiebolaget i Finland. Helsingfors, Citypassagen.

FRANCE
Société Française d'Electricité Asea, Paris, Boulevard Haussmann 114.

GREECE
Alexander Stavridès, Athens. Boulevard de L'Université, 43.

HOLLAND
Groeneveld, van der Poll & Co., Amsterdam, De Ruijterkade 41, 42.

INDIA
Ewing & Co. Ltd., Calcutta. 4, Clive Row.
The Consolidated Mills Supplies Ltd., Bombay, E. D. Sassoon Building. Dougall Ballard Estate.

JAPAN
Gadelius & Co., Tokyo, Yuraku-kwan, Yurakucho.
Kobe, 58 B, Naniwa machi.
Dairen, 45, Yu-ku, Satsumacho.

MEXICO
Compañía SKF Golfo y Caribe, S. A., Mexico, D. F., Av. 5 de Mayo No. 1.

NEW ZEALAND
A. S. Paterson & Co. Ltd., Wellington, 12 Cuba Street.

NORWAY
A/S Per Kure, Norsk Motor- og Dynamofabrik, Oslo, Universitetsgate 24.

PERU
Graham, Rowe & Co., Lima. Villalta 282.

POLAND
Towarzystwo Elektryczne Asea Warszawa. Kopernika Ul. 13.

PORTUGAL
Jayme da Costa Ltda, Lisbon, 16 Rua dos Correeiros 26.

RUSSIA
Asea, Leningrad, Uliza Gogolja 7.

SOUTH-AFRICA
Reunert & Lenz, Johannesburg. Consolidated Buildings.

SPAIN
Sociedad Española de Electricidad Asea, Madrid, Calle Montalbán 13.

Vesteras 1925, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

AS
EA

VOL. III
1926

PUBLISHED BY

ALLMANNA SVENSKA
ELEKTRISKA A.B.
VESTERAS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5. CHANCERY LANE — LONDON

INDEX

A S

E A

ASEA-JOURNAL

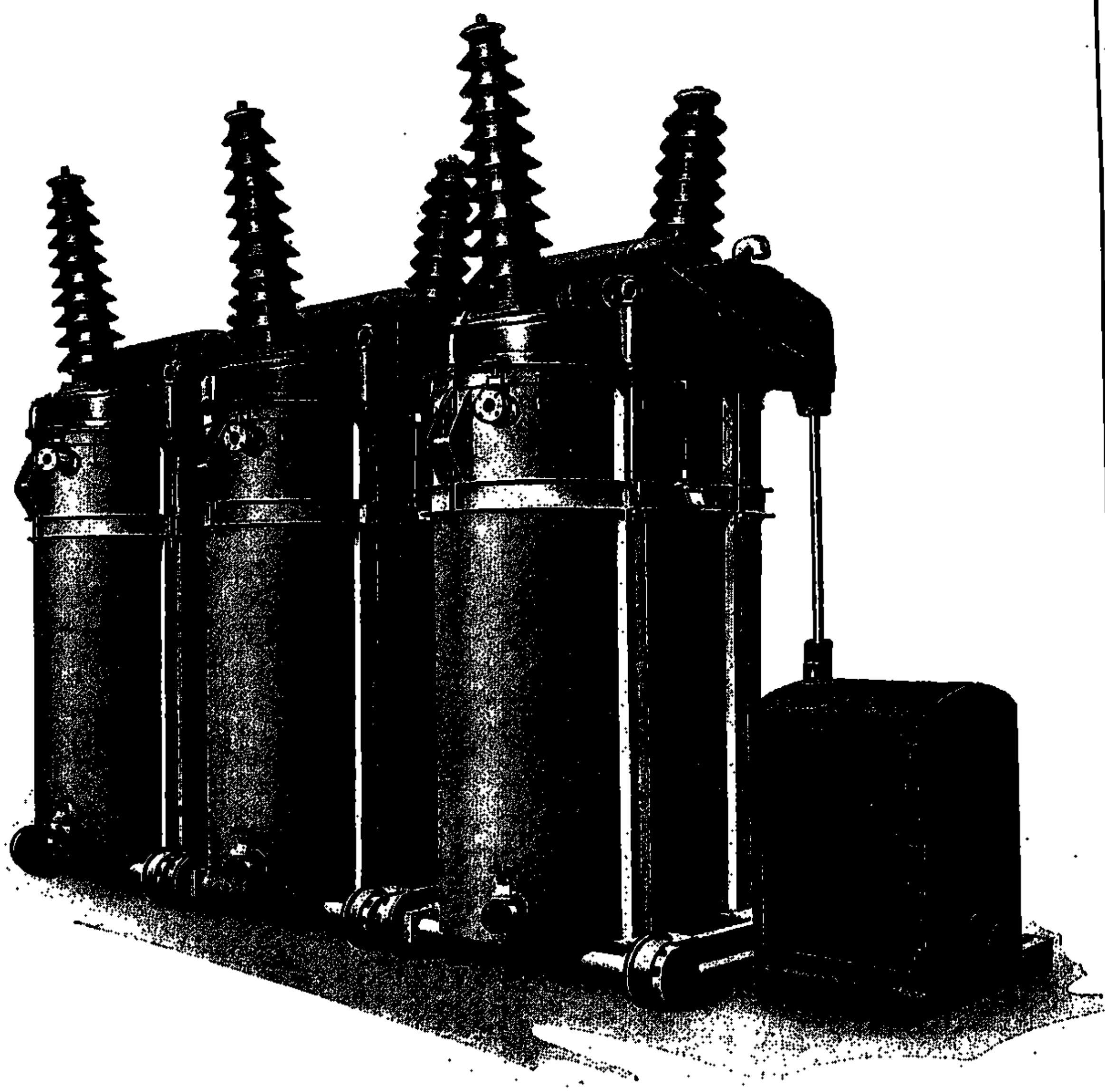
ALLMANNA SVENSKA
ELEKTRISKA A.B.
VESTERAS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

VOL. III
1926

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesteras, Sweden.

JANUARY
No. 1



3-pole automatic electrically operated oil switch for out-door erection, type HYGEU 130/350, 132 kV, 350 amps., for the Swedish Waterfalls Board.

AUTOMATIC POWER STATIONS.

During the last few years there has been continually increasing interest in automatically operated power stations, both in Sweden and abroad. In Sweden a number of proposals have been made regarding automatic working, and a few small stations have been put in operation where circumstances have been particularly suitable for automatic working, *i.e.* in cases where the position of the station has been unfavourable an alteration has been made to an automatic station. In other countries automatic stations have made greater strides. There are some stations as large as 5,000 kVA which are started and worked fully automatically. The reasons which have led to the construction of such large stations for automatic working have been the awkward, and in fact almost inaccessible positions. In many cases it would have been practically impossible to maintain a staff of supervising engineers in the places in which power has been available. The cost of maintaining the necessary personnel and their provisioning etc. would have been excessive.

This brings us to the chief advantage to be derived from the automatic working of a power station. It is possible in this way to

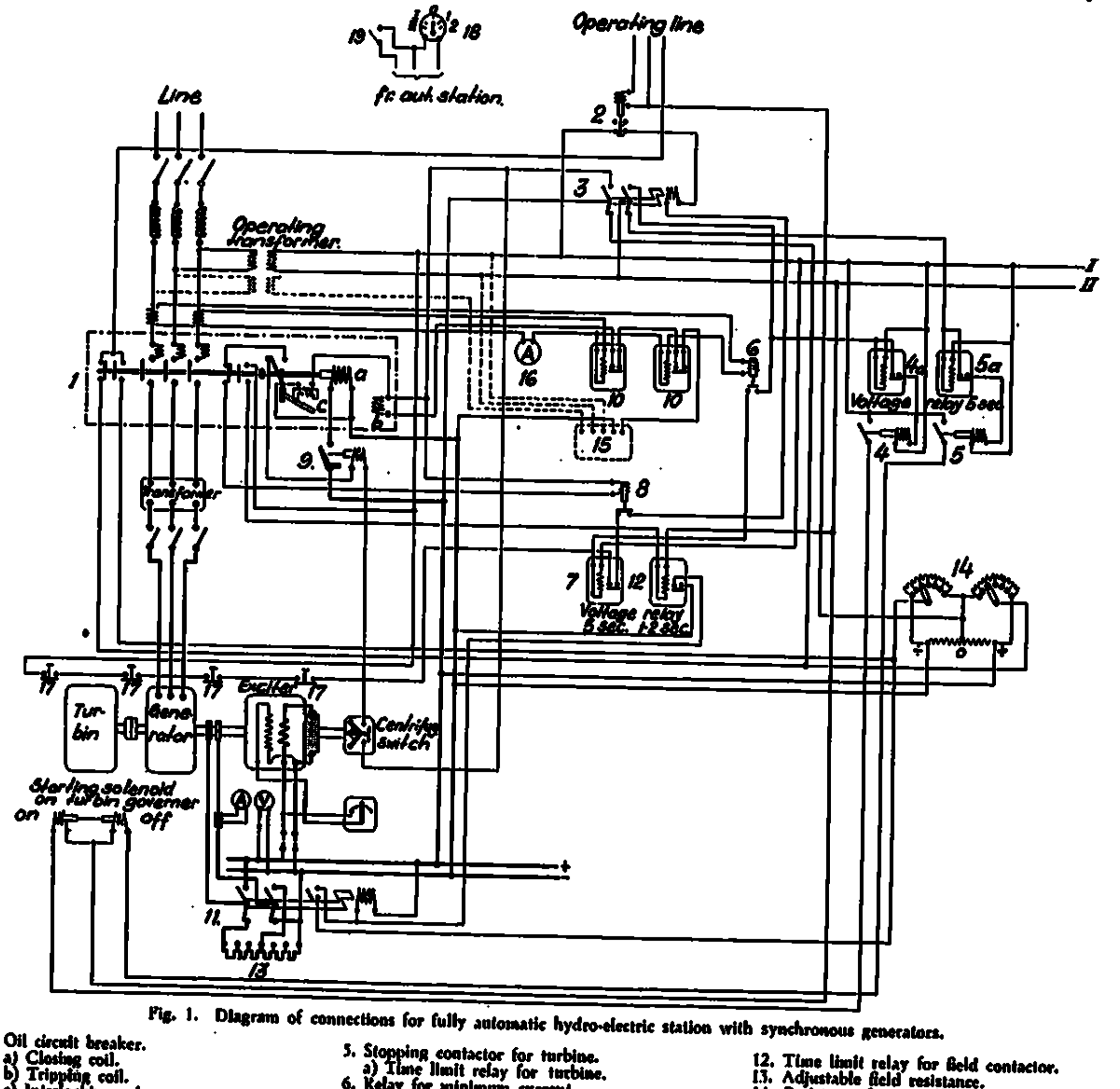
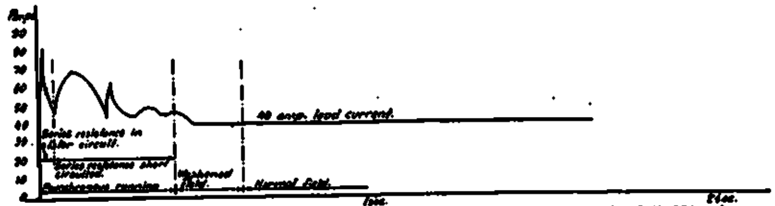


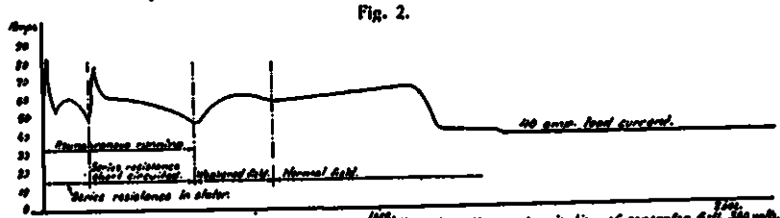
Fig. 1. Diagram of connections for fully automatic hydro-electric station with synchronous generators.

1. Oil circuit breaker.
   a) Closing coil.
   b) Tripping coil.
   c) Interlocking relay.
2. Intermediate relay.
3. Master control contactor.
4. Starting contactor for turbine.
4. a) Time limit relay for turbine.
5. Stopping contactor for turbine.
   a) Time limit relay for turbine.
6. Relay for minimum current.
7. Time limit relay (hand reset).
8. Auxiliary relay for oil circuit breaker (hand reset).
9. Operating contactor for oil breaker.
10. Overload relay for oil breaker.
11. Field contactor.
12. Time limit relay for field contactor.
13. Adjustable field resistance.
14. Resistance for signalling.
15. Reverse effect relay (eventual).
16. Ammeter.
17. Terminal relay for bearing.
In main station { 18. Indicator.
19. Change over switch for operating.



RMS value in amps. of stator current with automatic synchronisation of generator 4-11, 380 volts, 50 cycles. The poles have assumed correct position at once.

Fig. 2.



RMS value in amps. of the stator current with automatic synchronisation of generator 6-11, 380 volts, 50 cycles. The poles have assumed incorrect position during asynchronous running, and assume the correct position when the field is magnetised.

Fig. 3.

decrease the personnel, and thus wages and board and lodging expenses are spared. The work of the human element which is saved is replaced by apparatus,* relays etc., and attendants who usually are employed otherwise on repairs, meter-reading and so on but from time to time must visit, the station and do the inspecting work. On the other side we must reckon with new apparatus and the cost of setting it to work.

Before describing the various apparatus which is used, a few words must be said regarding the question in general.

1. *General Construction.*

When the matter of automatic operation of a station is being considered, a number of general questions regarding the working must be discussed. These have regard to the consideration as to how far automatic working can be pushed in order to obtain the most economical results.

If we reckon with the usual three shifts of attendants in a power station, it is possible by the installation of protective and safety devices to reduce this personnel to one shift, which by being more lightly employed can also visit the station in the night when they are warned by the signalling devices. The machinery attendants can in this way be employed on other work, an arrangement which is often practised even now without the use of such special safety devices.

Proceeding a step further, the personnel on a station can be entirely withdrawn, and supervision conducted from a distance, either from another station or from the industrial plant which the station is laid down to supply. This is the remote controlled station.

Finally, we come to the completely automatic station, which is started and stopped by means of contact wattmeters, water level indicators or similar devices.

A power station, however, cannot be run entirely without attendants. There must always be trained personnel available for regular inspection, oiling, and for keeping the plant in order. This personnel must also be available to proceed to the station when a signal is given that any fault has occurred. Suitable men are in general to be found at the main power station or works to which the station belongs, and any additional expense should not be incurred.

As regards attendance, three types of automatic stations can accordingly be cited.

1. Stations which are started, paralleled and stopped by an attendant on site. Here we only require a number of protective devices beyond the normal station equipment.

2. Stations which are started, paralleled and stopped from some distant point, *i.e.* so-called remote controlled stations. Here we require protective apparatus and also apparatus for starting, paralleling, stopping and signalling.

3. Stations which operate entirely automatically. This type have so far not been considered in this country, but abroad, such stations have been run with good results. Greater difficulties with them then with No. 2 should not be encountered here.

2. *Types of Machines, Voltage Regulation, Power Factor Correction, Load Regulation.*

If a station equipment already in existence is to be made automatic, we naturally endeavour to make use of the turbine and generator already installed. When a new equipment is to be put down the matter is somewhat different, and a number of constructional precautions can be taken, which will simplify the automatic operation. The selection of the type of generator is of considerable importance. We can choose either the synchronous or the asynchronous type. The former have considerable advantages in the electrical respect, both as regards efficiency and power factor correction. The latter, however, are of advantage with regard to simple starting, and they are not sensitive to variations in load. Asynchronous machines show considerable advantages where the station always runs at full load when it is in use. Such a case arises for example when a certain water reservoir is regularly emptied through the turbines of a power station. The turbine is shut down when the

water has been used up, and remains stationary until the water has again reached a certain height. The asynchronous generator can, however, never be used alone upon a supply system, but must always receive magnetising current from a synchronous generator. Attention may also be called to the compensated asynchronous machine, which can be used particularly well as an asynchronous generator. By this means bad power factor can be eliminated and the machine will run, practically speaking, at unity power factor from no load to full load.

One question which has a considerable effect on the equipment of an automatic power station concerns the arrangements to be made as regards parallel running with other stations, and the question of voltage regulation, power factor correction, division of load etc. We hold the view that in this respect as little dependence as possible should be placed on the automatic station. All arrangements for automatic voltage regulation, power factor correction and load distribution necessitate relatively involved apparatus which makes the plant more expensive, complicates the operation and, in accordance with our experience, gives rise to a lot of repair work.

If we assume accordingly that at first only the lesser stations on a supply system are to be made automatic, it is reasonable that complicated requirements need not be exacted from them. We can in this case overlook minor pressure variations and poor power factor on the lines connecting the main station and the automatic stations. The main power station can take care of the voltage regulation and power factor correction, the secondary stations being set for a suitable mean value with regard to the average power taken from them.

We shall return to the question of load division in another connection, and meanwhile transfer our attention to

3. *Arrangements with Water Turbines made necessary by Automatic Power Stations.*

Starting, stopping and division of load are effected by intimate reciprocal working of the turbine and generator, so that we may very well consider at this point some of the questions concerning the equipment of the turbine.

1. The gate mechanism is provided with a distant operated governor. For this the automatic starting device put on the market by the Mek. Verkstaden, Kristinehamn can very suitably be used. Electric motors are also used for operating the gate mechanism. For the electric operation of the servo-motor three leads must be used between the main station and the automatic station. It is, however, possible to use the same return connection for other circuits in the operating system, and so reduce the number of necessary conductors.

2. The speed of the turbine is controlled and kept constant by a governor which, for parallel running with another station, must allow of a certain amount of variation; the permanent speed drop between no load and full load should be approximately 2 %.

3. If power output regulation is to be controlled from a distance, a speed changing motor should be installed which can be controlled from the main station. A further two conductors are required for this purpose. In addition to the above, suitable wattmeter equipment must be installed in the main station from which the automatic station is controlled. The most simple arrangement is, however, to allow the automatic station to work with constant output as long as it is running, and do all the regulating at the main station so that the total output is equivalent to the demand and the frequency is kept constant. If the demand on the system sinks beyond a certain amount, the automatic station is shut down. It is started again when the demand has risen to such an extent that it can be fully loaded.

If running is arranged in this way it is possible to dispense with a speed regulating motor.

4. In case the demand suddenly ceases altogether, an overspeed regulator is required, which automatically shuts the station down if the speed of the sets increases beyond a certain amount. The automatic starting gear of the Kristinehamn Company referred to above is designed to deal with this question also. A further protection against runaway is to arrange a special by-pass valve in the pipe line which opens and allows the water to go past the turbine in the event of the pressure in the pipe increasing suddenly beyond a certain maximum.

5. Lastly, it is usually most desirable to have a good indication of the head of water available at the automatic station. For this purpose various apparatus has been developed by L. M. Ericsson, Siemens etc. For indicating the head of water two conductors must be installed between the stations. One, however, can in most cases be dispensed with by making use of the common return lead for all operating circuits.

All the points referred to above concern the water turbine, and generally speaking all turbine firms now equip their machines so that all the requirements mentioned are met.

4. *Electrical Equipment.*

In an automatic plant the electrical equipment consists of apparatus and conductors for start-

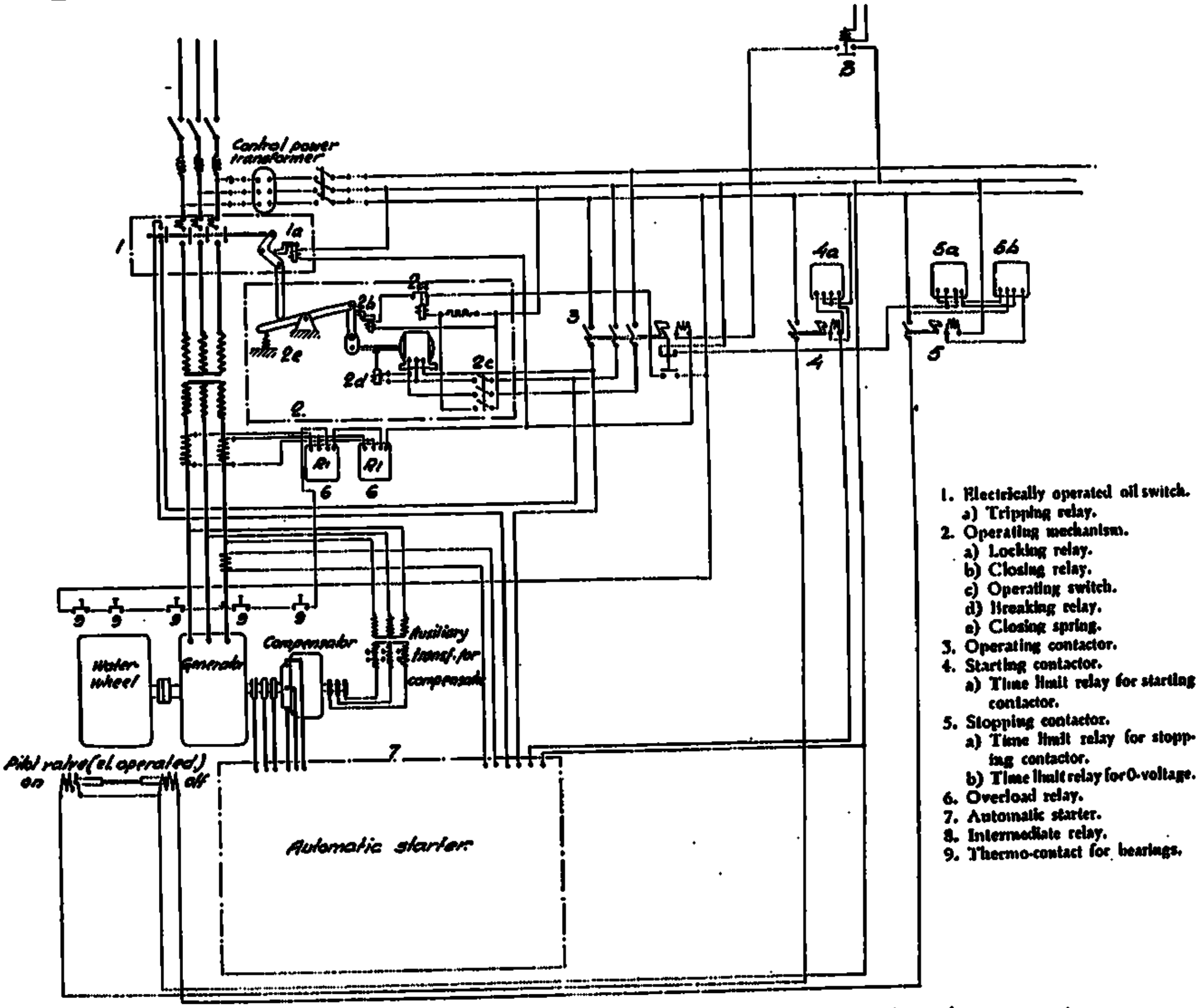


Fig. 4. Diagram of connections for fully automatic hydro-electric station with compensated asynchronous generator.

ing, synchronising, stopping, protection, and distant operation.

With the assistance of fig. 1, which shows the diagram of connections for a station containing synchronous machinery and running automatically, the method of starting will be shortly described. A starting impulse is given to the station and is sent through relay No. 2 on to the automatic starting apparatus of the turbine. The turbine is set in motion and the speed is gradually increased. In the neighbourhood of synchronism and at about 5 to 2 % below, the centrifugal switch closes and connects oil switch No. 1 in circuit. The generator is thrown on the supply and runs as an asynchronous machine with approximately normal full-load current. Immediately afterwards the field of the machine is excited, at first with a feeble current and finally with full load exciting current. Due to this, the poles assume the correct phase position and the generator is synchronised. If the poles should have been in the incorrect position to start with, the current of the generator increases for an instant (about one-half of a second) to double the normal current, and afterwards returns to the load value corresponding to the load on the machine at the time.

Figs 2 and 3 show by means of oscillograms the whole variation of the current for a 30 kVA generator under conditions as nearly approximating to those of actual service as possible.

An asynchronous station provided with power factor correction is shown in fig. 4 and is started in the following manner. The starting impulse is given to relay No. 8 and is by this means taken to the automatic starter No. 7 and the oil switch No. 1. The generator runs up as a

normal induction motor, speeding up the turbine at the same time. When full speed is attained, the gate of the turbine is opened by the automatic starter and the station can then take up its load.

The operations described above are carried out automatically by oil switches and contactors controlled from the main station. It would take up too much space here to describe these arrangements more fully, and we shall accordingly turn to a brief review of the protective apparatus.

It was pointed out before that, in our opinion, the arrangements for voltage regulation, power factor correction etc. should be as simple as possible, and as regards protective devices, these should similarly be reduced to the smallest number absolutely necessary. Such protection includes

1. Overload protection.
2. No-volt protection.
3. Reverse current protection.
4. Warnings of hot bearings in generators and turbines.

Overload, no-volt, and reverse current protection is arranged in a similar manner to that adopted in ordinary stations, and brings about disconnection from the network when any fault occurs. At the same time, however, the turbine must be stopped and a warning given in the main station to show what has occurred. This is all done automatically. The attendants at the main station can re-start when the fault is of a transient nature. If after paralleling, the station is again shut down, the reason for the trouble must be further investigated and removed.

The occurrence of a hot bearing is a fault which necessitates the despatch of a competent man to the station. The question is only as to whether the signal device should be of a kind which gives timely warning as soon as a temperature rise greater than normal begins to occur, so as to summon help, or whether it should be of the pattern which acts merely by shutting the station down when a predetermined critical value has been reached. The former system is probably the most desirable, but makes it necessary to duplicate the thermal devices in the bearings.

Reference must lastly be made to another most important detail which concerns the operating system and signalling instruments.

The question as to where the operating current shall be obtained is in some cases rather a problem. In general this can be arranged in the following manner.

In the main station there is placed an master switch for starting and stopping, and an indicator which shows at all times the running condition of the secondary station. The current for starting, stopping and indicating is taken from the main station when all the conductors in the secondary station are dead. In general this gives rise to no difficulty, as in any case exciting current is always available. In the worst case it is possible to carry on by using an accumulator battery of something under 100 volts which in this case is then placed in the automatic station and is chiefly intended for operating the starting solenoid of the turbine. Continuous current can be transmitted about 5 kilometres without difficulty, and this is sufficient in most cases. When the distance is greater it is possible to make use of small relays.

Current for operating oil switches, contactors, operating motors etc. must be taken from the automatic station or from the network. With synchronous machinery the exciter is always available, and with asynchronous generators AC can be taken from the net for operating and also for lighting during repairs etc.

Indicating signalling can be simply arranged with the help of a voltmeter with a special scale. If we are content to use five operating positions, only two conductors are necessary between the two stations. These five positions give the following:

1 is used during starting and synchronising.
2 during normal running.
3 during stopping.
4 when the station is not working and everything is correct for a new start.
5 is an emergency signalling positions for use when something is wrong. In this position an alarm bell or lamp signal is connected for attracting attention.

The complete remote controlled station in accordance with the foregoing description requires the following operating leads:

3 for starting, stopping and signalling.
2 for the water level indicator.
5 for load regulation.

If load regulation is not embodied and a common return lead is used, the number of conductors can be reduced to four.

We have attempted here to give a brief description of the questions which have to be considered in connection with making a power station automatic. The treatment is naturally not exhaustive in any direction, and the nature of the case necessitates that local conditions always affect the arrangement adopted. At the same time, we hope that we shall in the near future be making use of the advantages offered by automatic operation, which have been found possible abroad, particularly in reducing the running cost on existing installations and in making possible the utilisation of small amounts of water power which would not otherwise be a commercial possibility.

132 kV OIL SWITCH FOR THE SWEDISH WESTERN MAIN LINE ELECTRIFICATION.

The Stockholm—Gothenburg railway line is being supplied from five substations, to which the Royal Waterfalls Board are supplying power in the form of high tension three-phase current.

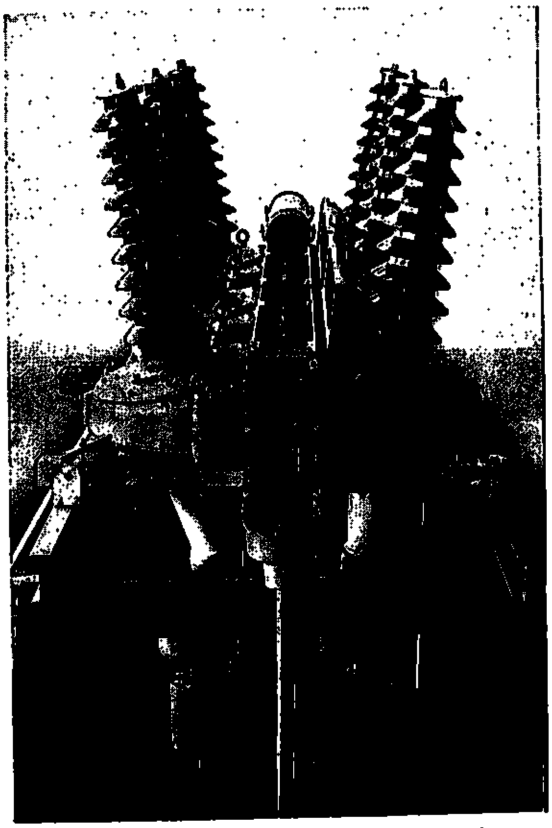


Fig. 1. Oil switch type HYGEU 130/350 viewed from above.

For the substations at Hallsberg and Moholm, which are supplied from the power station at Trollhattan via the Western Power Line, Asea has just supplied the necessary 132 kV oil switches.

These are designed for out-door erection, 300 amps. normal current and a breaking current of 2,400 amps. at a working pressure of 132 kV. They are designed to withstand a test pressure of 275 kV for one minute. The flash-over voltage for the terminals exceeds 320 kV dry and 275 kV on rain test.

The oil switches are built up of three single pole units, for which the oil tanks are provided with flanged wheels to run on rails for shifting. Each unit consists of a heavy cast iron cover, or base-plate, which is carried on the oil tank. The contact arrangement and the mechanism are supported by this cover. The lifting rod for the contact bridge, together with the parallel guide mechanism and system of operating links, are contained in the cover, but are easily accessible through removable inspection lids suitably arranged.

The oil switch bedplate or cover, and the oil tank, are held together with heavy bolts. The joint between cover and tank is provided with watertight packing. The cover has four eyebolts, for lifting the complete switch, or for lifting the working parts of the switch out of the oil tank. The single pole elements of the switch are mechanically connected by a self-contained rod system which is carried to a separate motor driven operating arrangement.

A free tripping device is provided and all necessary signalling and auxiliary contacts. In the casing for the operating arrangement is placed a terminal board for the operating circuits. Closing can also be effected by hand, by means of a removable lever, and tripping can be carried out by means of a special handle. The position of the switch is indicated by a mechanically operated signalling device. The operating arrangement requires relatively little power for

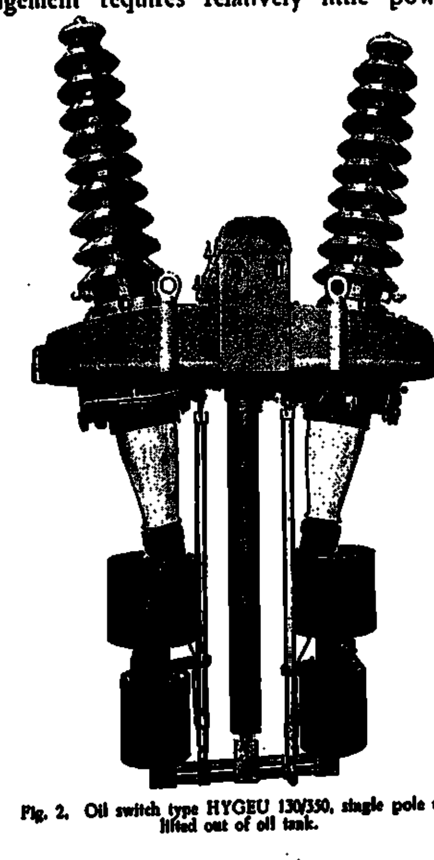


Fig. 2. Oil switch type HYGEU 130/350, single pole unit lifted out of oil tank.

closing (approx. 2 kW) and it moves particularly smoothly and rapidly. It is so arranged that the power supplied by the motor is stored

in a flywheel, which is coupled up to the link mechanism of the switch through a clutch and gear when the switch is to be closed, and uncoupled when this operation is completed.

Opening of the switch is effected by the downward movement of the contact bridge, there being two breaks per pole. The contacts are of the plug type. The fixed parts, which are carried on the leading through bushings, are enclosed in explosion chambers.

The switches are fitted with charging resistances which are connected in circuit for closing by special contacts before the main contacts are closed, and are afterwards short circuited. The charging resistances consist of resistance mats wound in rolls and mounted in bakelite paper cylinders, placed above the explosion chambers. The fixed charging resistance contacts are supported on bakelite paper tubes.

The leading through bushings are of the condenser type with porcelain sheaths. They are provided with cast iron flanges screwed to the switch covers.

The switches are further fitted with self-contained current transformers carried in circular brackets round the leading through insulators. These last can be dismantled without moving the transformers. The terminals of the secondary winding are brought to a plug fitting on the top of the switch cover, from which conductors are run in tubing to the terminal board in the casing of the operating gear.

The switch tanks are built up from heavy plate, and fitted with oil gauges and filling and draw-off valves.

The flanged wheels for the oil tanks are designed for a gauge of 1,435 mm and are provided with barring arrangement.

THE USE OF NOMOGRAMS AS A HELP IN TRANSFORMER CALCULATIONS.

The use of nomograms is of great assistance to those who are not fully conversant with mathematical calculations and to whom the handling of more or less complicated formulars is difficult and wasteful of time, and also to others who, like estimating engineers, although familiar with mathematics, have to carry out the same calculations several times a day.

The object of this article which deals with one or two of the simplest nomograms and their construction, is to indicate the mathematical foundation of such diagrams, and to make the users of the diagrams conversant with their construction. The idea is also to show how simple the construction actually is in most cases, and to give a stimulus to the use of such diagrams and charts which can be of the greatest assistance in all technical calculations.

The diagrams described in the following have been designed to assist work in the estimating departments of Asea, and their use has given exceedingly good results for more than a year.

A nomogram or chart consists of three or more straight or curved scales for three or more inter-dependent variables, the scales being so divided as to have the property that the mutually connected values of the variables lie in a straight line, *i.e.*, if the values of two of the variables are known the corresponding value of the remaining variable can be read off at the point of intersection between the respective scale and a straight line drawn through the points on the other scales which correspond to the known values. In the simplest cases all the scales are straight, and it is one or two of these special cases which are dealt with below.

Referring to fig. 1 for a mathematical deduction, AD, BE and CF are three parallel straight lines. ABC, DEF, etc., are straight lines which cut the three parallel lines. Geometrically we obtain:

$$GE = AD \cdot \frac{BC}{AC} - BH; \; BG = CF \cdot \frac{AB}{AC} - HE$$

$$\therefore BH + HE = BG + GE = BE = AD \cdot \frac{BC}{AC} + $$

$$+ CF \cdot \frac{AB}{AC} \quad \ldots\ldots\ldots\ldots \quad (1)$$

The distance BE is accordingly equal to the sum of AD and CF each reduced in a certain ratio, for any points D, E and F provided that these lie in a straigth line and on the respective parallel lines. The whole problem is thereby solved. For instance setting up on the line AD a linear scale representing a variable X, so that the origin of the scale lies at A and $AD = \alpha X$, and on the line CF a linear scale representing a variable Y, so that the origin lies at C and $CF = \beta Y$, and on the line BE a linear scale representing a variable Z so that the origin lies at B and $BE = \gamma Z$, then in accordance with equation 1 there is a connection between X, Y and Z,

$$\alpha X \frac{BC}{AC} + \beta Y \frac{AB}{AC} = \gamma Z \quad \ldots\ldots \quad (2)$$

On the assumption that the connection between X, Y and Z is represented by equation 2, we

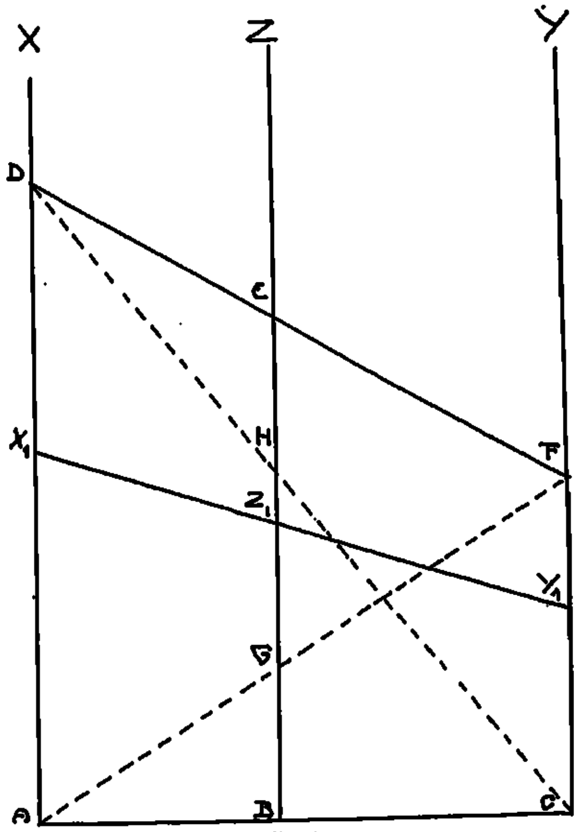


Fig. 1.

can accordingly find for any values X_1, Y_1 on X and Y a corresponding value Z_1 on Z by joining X_1, Y_1 by a straight line which cuts the Z scale at Z_1. Generally equation 2 can be written:

$$f_1\,X+f_2\,Y=f_3\,Z \quad \ldots\ldots\ldots\ldots (3)$$

and this equation can be represented by scales on three parallel straight lines, and mutually connected values of X, Y and Z are obtained at points of intersection between a straight line and the three scales. If f_1, f_2 and f_3 are constants the three scales are linear, and the connection between AB, AC, BC, α, β, γ and f_1, f_2 and f_3 in equations 2 and 3 is as below:

$$AB=AC\frac{\frac{f_2}{\beta}}{\frac{f_1}{\alpha}+\frac{f_2}{\beta}};\ BC=AC\frac{\frac{f_1}{\alpha}}{\frac{f_1}{\alpha}+\frac{f_2}{\beta}};$$

$$\gamma=\frac{f_3}{\frac{f_1}{\alpha}+\frac{f_2}{\beta}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

In constructing the diagram a suitable value is chosen for the length AC. The value of the scales α and β is chosen so that the actual divisions of the X and Y scales respectively are of suitable length. (The calculation of α and β is carried out for one case in the following). As in equation 4 all the magnitudes with the exception of AB, BC and γ are known, these last can be determined and the diagram constructed. f_1, f_2 and f_3 can be positive or negative, but care must be taken that the positive directions are reckoned in the same direction from the origins of the different scales. As regards the origins of the scales (A, B, C in fig. 1) these, further, must lie on the same straight line, but this (A—C) need not be at right angles to the X, Y and Z scales as shown in fig. 1. If, for example, in a certain case only a small part of the scale of one variable (e. g. X between 10 and 20) is of actual use, the origin for this scale is chosen so that its lowest useful value ($X=10$) lies at the same height as the origin, for example, of one of the remaining scales, ($Y=0$), if this scale is used from the origin upwards. The remainder of the first scale need not be drawn. In the same way the third scale need not be drawn for the whole of its length, but its magnitude and position can be determined exactly as above.

If f_1, f_2 or f_3 are not constants $f_1\,X$, $f_2\,Y$, $f_3\,Z$ representing any functions of X, Y and Z respectively, we can put $f_1\,X=\varphi_1\,\xi : f_2\,Y=\varphi_2\,\zeta$ and $f_3\,Z=\varphi_3\,\eta$, where φ_1, φ_2 and φ_3 are constants. The diagram is then constructed for the function $\varphi_1\,\xi+\varphi_2\,\zeta=\varphi_3\,\eta$ in accordance with the above with a ξ- a ζ- and a η-scale. Then since for each value of ξ there is a corresponding value of X, for each value of ζ a certain Y-value, and for each value of η a certain Z-value, we can set up on the ξ-scale a corresponding X-scale etc. The scale for X, Y and Z are therefore in most cases not linear, but may be quadratic, or logarithmic, or of some other type depending on the appearance of the different functions. As the ξ, ζ and η-scale are only for assistance in construction they are not given in the final diagram, but only the corresponding X, Y and Z-scales are included.

In accordance with the foregoing for any function whatever, $f_1\,X+f_2\,Y=f_3\,Z$ of three variables we can construct a nomogram, and where two of the variables are known, determine the value of the third by seeking the known values on the diagram (e.g. X_1, Y_1) on the respective scales, and joining these points by a straight line, when the corresponding value (Z_1) of the third variable (Z) can be read at the point of intersection between the straight line and the third scale (the Z-scale).

A simple application of the above is the construction of a nomogram for the determination of the voltage drop in a transformer with different loads and power factors. (As the same

formulae also hold for the voltage drop in lines, the same diagram can be used for determining the voltage drop in a supply line, but only in the case where the power factor and load is positive and the inductive voltage drop on the line is greater than the capacity effect).

We introduce the following symbols:

E_r = total ohmic voltage drop in the transformer in % of the primary voltage.

E_x = total reactive voltage drop in the transformer in % of the primary voltage.

E_k = the short circuit voltage of the transformer in % of the primary voltage.

Cos φ_2 = the power factor of the secondary load.

E_φ = the total voltage drop in the transformer with a certain power factor cos φ_2 of the secondary load in % of the primary voltage.

Then with sufficient exactness:

$$E_\varphi = E_r \cos \varphi_2 + E_x \sin \varphi_2 + \frac{10^{-2}}{2}(E_r \sin \varphi_2 - E_x \cos \varphi_2)^2 + \frac{10^{-6}}{2,4}(E_r \sin \varphi_2 - E_x \cos \varphi_2)^4 + \frac{10^{-10}}{2,4,6}(E_r \sin \varphi_2 - E_x \cos \varphi_2)^6 + \ldots\ldots\ldots \quad (5)$$

$$E_k^2 = E_r^2 + E_x^2 \ldots\ldots \quad (6)$$

Equation 5 is far too complicated for use in ordinary technical calculations and we must be content with the less exact formula

$$E'_\varphi = E_r \cos \varphi_2 + E_x \sin \varphi_2 \ \ldots\ldots\ldots\ldots \quad (7)$$

This formula however gives, for large transformers in which E_x can be 10—12 times E_r, with cos φ_2 = 1.0 values up to 50% too small for E_φ, so that, in many cases at least, the first of the neglected terms must be taken. This, as we have said before, makes the formula awkward to handle, but with the help of the line diagram this difficulty is easily overcome. As the formula $E_\varphi = E'_\varphi$ gives sufficiently accurate results in many cases, two diagrams can suitably be drawn, one for $E'_\varphi = E_r \cos \varphi_2 + E_x \sin \varphi_2$ and one for

$$E''_\varphi = \frac{10^{-2}}{2}(E_r \sin \varphi_2 - E_x \cos \varphi_2)^2 + \frac{10^{-6}}{2,4}(E_r \sin \varphi_2 - E_x \cos \varphi_2)^4 + \frac{10^{-10}}{2,4,6}(E_r \sin \varphi_2 - E_x \cos \varphi_2)^6 + \ \ldots\ldots \quad (8)$$

when accordingly $E = E'_\varphi + E''_\varphi$.

Nomogram for E'_φ.

We can write equation 7 in the form

$$f_1 X + f_2 Y = f_3 Z.$$

where $X = E_r$; $Y = E_x$; $Z = E'_\varphi$; $f_1 = \cos \varphi_2$; $f_2 = \sin \varphi_2$; $f_3 = 1$.

The diagram accordingly will have linear scales for X, Y and Z.

Returning to equation 4 in the foregoing, we have first to determine AC, α and β. To make the diagram of convenient size we choose $AC = 15$ cm. The diagram is constructed for E_r and E_x between 0 and 12%. If the scales for E_r and E_x are chosen the same and so that a length of 10 cm represents 5%, the height of the whole diagram is 24 cm and we obtain $\alpha = \beta = 2$. ($AD = 10 = \alpha \cdot 5$; $\alpha = 2$; $CE = 10 = \beta \cdot 5$; $\beta = 2$).

From this we obtain accordingly:

$$AB = 15 \cdot \frac{\frac{\sin \varphi_2}{2}}{\frac{\cos \varphi_2}{2} + \frac{\sin \varphi_2}{2}} = 15 \cdot \frac{\sin \varphi_2}{\cos \varphi_2 + \sin \varphi_2}$$

$$BC = 15 \cdot \frac{\cos \varphi_2}{\cos \varphi_2 + \sin \varphi_2}$$

$$\gamma = \frac{2}{\cos \varphi_2 + \sin \varphi_2}$$

For every value of cos φ_2, we accordingly obtain a scale for E'_φ, and these scales are drawn

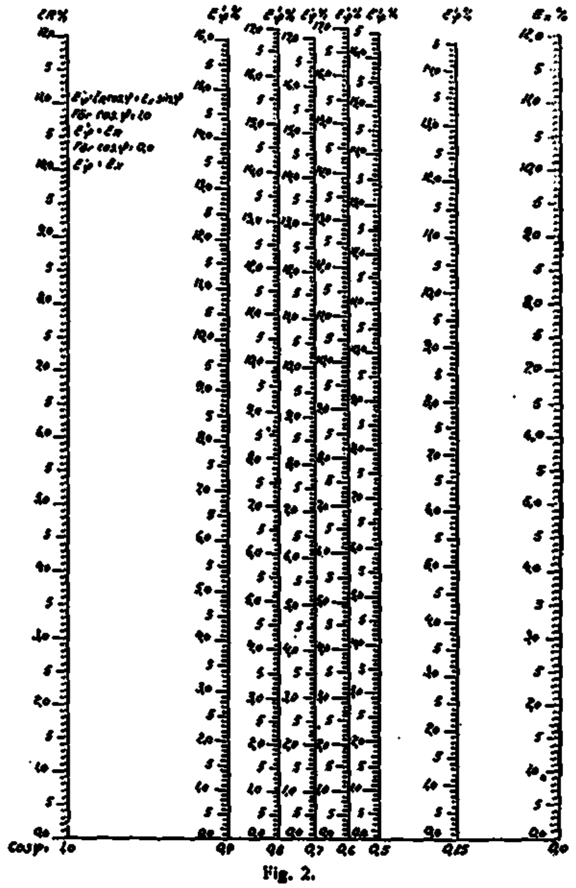


Fig. 2.

for the most commonly occuring values of $\cos\varphi_2$, namely $\cos\varphi_2 = 1.0, 0.9, 0.8, 0.7, 0.6, 0.5, 0.25, 0.0$. In the following table the values obtained for AB, BC and γ are given.

$\cos\varphi_2$	AB	BC	γ
1	0	15	2
0.9	4.90	10.10	1.495
0.8	6.44	8.56	1.428
0.7	7.57	7.43	1.414
0.6	8.56	6.44	1.428
0.5	9.51	5.49	1.465
0.25	11.92	3.08	1.645
0.0	15.00	0.00	2.00

It is evident from this table that when $\cos\varphi_2 = 1.0$ the scale for E'_φ exactly concides with the scale for E_r and with $\cos\varphi_2 = 0.0$ the scale for E'_φ exactly concides with the scale for E_x. The remaining scales come between these two outer scales.

The appearance of the diagram is in accordance with fig. 2. The diagram is most conveniently drawn on millimetre squared paper, but should afterwards be copied on to plain paper so that the millimetre divisions do not interfere with the use of the diagram.

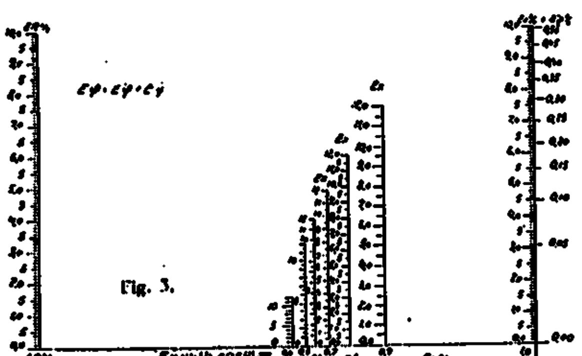


Fig. 3.

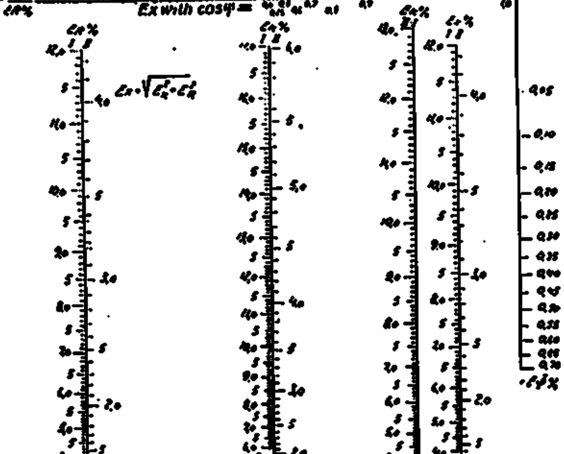


Fig. 4.

Nomogram for E''_φ.

The expression for E''_φ cannot be written directly in the formula $f_1 X + f_2 Y = f_3 Z$ but if we put $E_r \sin\varphi_2 - E_x \cos\varphi_2 = Z$, it is clear that according to equation (8) $E''_\varphi = \frac{10^{-2}}{2} Z^2 + \frac{10^{-6}}{2,4} Z^4 + \frac{10^{-10}}{2,4,6} Z^6 + \ldots\ldots\ldots$ *i.e.* every value of Z determines at the same time one value of E''_φ. We can accordingly draw a nomogram for the function $E_r \sin\varphi_2 - E_x \cos\varphi_2 = Z$ and replace the Z-scale directly by an E''_φ scale whence a nomogram for the connection between E_r, E_x and E''_φ is obtained for different values of the power factor. Here, however, we encounter a difficulty. If the calculation is done as for the E'_φ diagram we obtain $f_1 = \sin\varphi_2$; $f_2 = -\cos\varphi_2$ and $f_3 = 1$ and accordingly $AB = -AC \frac{\cos\varphi_2}{\sin\varphi_2 - \cos\varphi_2}$; $BC = AC \cdot \frac{\sin\varphi_2}{\sin\varphi_2 - \cos\varphi_2}$; $\gamma = \frac{2}{\sin\varphi_2 - \cos\varphi_2}$ *i.e.* for $\cos\varphi_2 = \sin\varphi_2 = 0.707$ AB, BC and γ are infinite or, in general, for $\cos\varphi_2$ in the neighbourhood of $\sin\varphi_2$ the E''_φ scales are extended a long way from the E_r and E_x scales. In order to get a suitable shape of diagram we accordingly put $E_r = X$, $E_x = Z$ and $E''_\varphi = \frac{10^{-2}}{2} Y^2 + \ldots\ldots$ and in equation (4) we obtain $f_1 = \sin\varphi_2$, $f_2 = 1$, $f_3 = \cos\varphi_2$. Proceeding now in the same way as for the E'_φ-diagram we obtain as a result the diagram shown in fig. 3. This diagram has the drawback that for given values of E_r and E_x the value of E''_φ for different values of $\cos\varphi_2$ cannot be obtained by one position of the reading line, but this must be moved for every value of $\cos\varphi_2$. This disadvantage is, however, made up for by the fact that the value of E''_φ with $\cos\varphi_2 = 1.0$ is independent of the value of E_r and can accordingly be read directly on the E_x scale, partly because in most cases the voltage drop is not of interest for more than one value of $\cos\varphi_2$ beyond $\cos\varphi_2 = 1.0$. The diagram shows that E''_φ is relatively small as long as $\cos\varphi_2 < 0.8$ and when E_x and E_r respectively are $< 5\%$, so that E''_φ can then be neglected in relation to E'_φ. After working with this diagram for some time it is almost possible to determine E''_φ with sufficient accuracy without reference to the diagram at all, so that it is particularly simple in practical use.

The alteration of the Y-scale to the E''_φ-scale is in this case most simply carried out by determining values of E''_φ for different values of Y, drawing a curve of the connection between E''_φ and Y, and from this curve determining

corresponding values of Y for certain even values of E''_{φ}. The E''_{φ} scale is then graduated from the values obtained as it is not linear. In the construction of nomograms in general, the greatest importance is attached to the division of the actual scales, as the correctness obtained by the use of the diagram depends on how accurately the scales are constructed.

Nomogram for the connection between E_k, E_r and E_x.

This diagram gives a simple example of a ruler diagram with quadratic scales. In accordance with the above we have

$$E_k^2 = E_r^2 + E_x^2$$

putting here $E_r^2 = X$, $E_x^2 = Y$, $E_k^2 = Z$ we obtain $X+Y=Z$, and accordingly $f_1 = f_2 = f_3 = 1.0$.

The diagram for $X+Y=Z$ is calculated as the E'_{φ} diagram, and the E_k, E_r and E_x scales are determined by finding corresponding X, Y and Z values for certain even values of E_k, E_r and E_x, and afterwards drawing the respective scales from the results obtained. The result of this is shown in fig. 4. It will be noticed in this diagram two E_r, two E_x and three E_k scales must be constructed, because the quadratic scales are less exact in the neighbourhood of the origin and special scales must be constructed for low values of E_r, E_k and E_x respectively. The scales which can be used together are the scales denoted by I, those denoted by II and E_r scale II, E_k scale II—I and E_x scale I.

Thus all the diagrams for the determination of the voltage drop in transformers are given and may be used as follows. Normally a value is guaranteed for the short circuit voltage and the ohmic voltage drop. From these a value is determined in accordance with fig. 4 for the reactance voltage drop E_x, and from the values of E_r and E_x in accordance with the diagram in fig. 2 E'_{φ} for any desired power factors on the secondary side, and lastly in accordance with the diagram fig. 3 E''_{φ} if necessary.

A Nomogram for the determination of efficiency.

The following symbols are introduced:

W = the secondary output of the transformer with $^1/_1$ load and $\cos\varphi_2 = 1.0$ in VA.

λ = the copper losses with $^1/_1$ load and $\cos\varphi = 1.0$ in % of W.

ε = the iron losses with $^1/_1$ load and $\cos\varphi = 1.0$ in % of W.

u = secondary output in relation to W.

$\cos\varphi_2$ = power factor of the secondary load.

η = the efficiency of the transformer with secondary load $\cos\varphi_2 \cdot u \cdot W$ Watts in %.

ηf = percentage of losses with efficiency η.

Then:

$$\eta = 100 - \frac{\dfrac{u^2 \cdot \lambda \cdot W + \varepsilon W}{100}}{\cos\varphi_2 \; u \cdot W + \dfrac{u^2 \lambda W + \varepsilon W}{100}} \cdot 100$$

$$= 100 - \frac{100}{\dfrac{\cos\varphi_2 \cdot u}{u^2 \lambda + \varepsilon} \cdot 100 + 1} \quad \ldots\ldots (9)$$

Assuming first that $\cos\varphi_2 = 1.0$ and putting $\dfrac{\cos\varphi_2 \cdot u}{u^2 \cdot \lambda + \varepsilon} = \dfrac{1}{v}$ we get

$$\eta = 100 - \frac{100}{\dfrac{100}{v} + 1} \quad \ldots\ldots\ldots\ldots (10)$$

From this it follows that η is determined in terms of v, *i.e.* for every value of v there is only one corresponding value of η. We accordingly calculate a nomogram for the function $u\lambda + \dfrac{1}{u}\varepsilon = v$, as the nomogram for E'_{φ} and hence put $f_1 = u$, $f_2 = \dfrac{1}{u}$ and $f_3 = 1$. The diagram

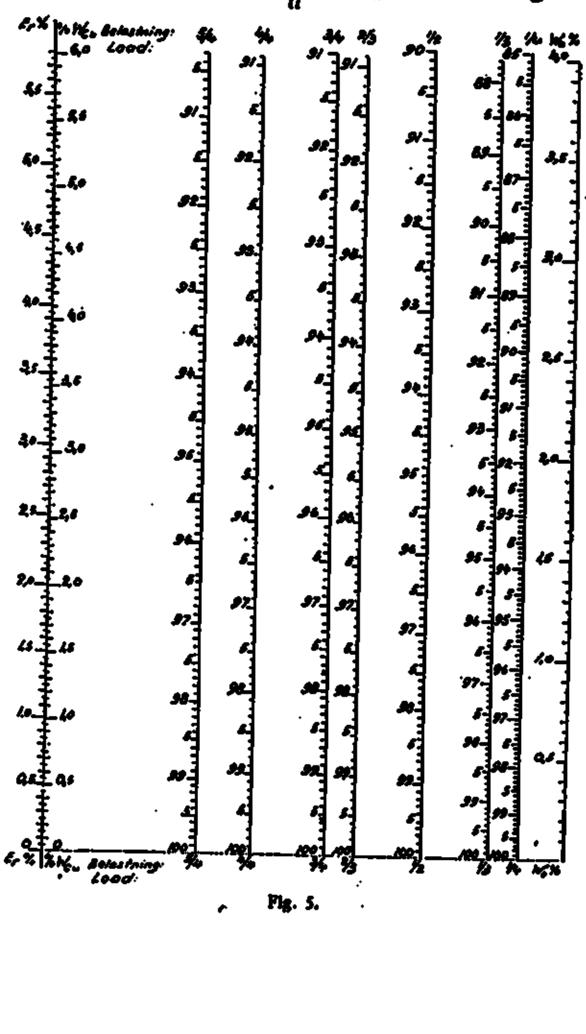


Fig. 5.

is linear with respect to λ, ε and ν and we obtain a ν-scale for every value of u, the ν-scale being drawn for the most commonly required values of u $\left(\frac{5}{4}, \frac{4}{4}, \frac{3}{4}, \frac{2}{3}, \frac{2}{4}, \frac{1}{3} \text{ and } \frac{1}{4}\right)$. Transformation of the p-scales into η-scales is done most simply by putting $\eta = 100 - \eta f$ and determining ν as a function of ηf. We then obtain

$$\nu = \frac{\eta f}{1 - \frac{\eta f}{100}}$$

and in accordance with this equation the value of ν is determined for certain values of ηf. The value of η is then directly given for the respective ηf values. The appearance of the resulting diagram is in accordance with fig. 5. The λ-scale is here denoted by W_{cu} and the ε-scale by W_o. By the help of this diagram accordingly, if the efficiencies for a transformer at e.g. $^1/_1$ and $^1/_2$ load are known at $\cos\varphi_2 = 1$, the efficiencies at $^5/_4$, $^3/_4$, $^2/_3$, $^1/_3$ and $^1/_4$ load, and the copper and iron losses with $^1/_1$ load and $\cos\varphi = 1.0$ can be directly determined as a percentage of the secondary load by the points of intersection between the respective scales and a straight line drawn through the points of known efficiency. It will be seen from the diagram that a scale for ohmic voltage drop E_r is also marked on the W_{cu}-scale so that it is possible to obtain the ohmic voltage drop direct from the diagram. The E_r-scale is determined in accordance with the formula $E_r = \frac{\lambda \cdot 100}{100 + \lambda}\%$, which gives a sufficiently close result.

In the foregoing the efficiency diagram holds for $\cos\varphi_2 = 1.0$, but it can also be used for other values of the power factor. We can write equation (9) in accordance with the formula

$$\eta = 100 - \frac{100}{\dfrac{u}{u^2 \dfrac{\lambda}{\cos\varphi_2} + \dfrac{\varepsilon}{\cos\varphi_2}} \cdot 100 + 1};$$

Thus if we work with $\lambda_1 = \frac{\lambda}{\cos\varphi_2}$ and $\varepsilon_1 = \frac{\varepsilon}{\cos\varphi_2}$ instead of with λ and ε the diagram must hold good without alteration, and with the assistance of the diagram, the efficiency at any desired value of $\cos\varphi_2$ can be determined. If for example in a certain case the efficiencies of a transformer are known at $^1/_1$ and $^1/_2$ load with $\cos\varphi_2 = 1$, the remaining efficiency figures and corresponding values of λ and ε are determined in accordance with the foregoing. If the efficiency of the transformer is to be determined with $\cos\varphi_2 = a$ for the secondary load we determine $\lambda_1 = \frac{\lambda}{a}$, $\varepsilon_1 = \frac{\varepsilon}{a}$ and find the corresponding points on the W_{cu} and W_o-scales. A straight line is drawn through these points and the required efficiencies read off at the points of intersection between this straight line and the respective scales.

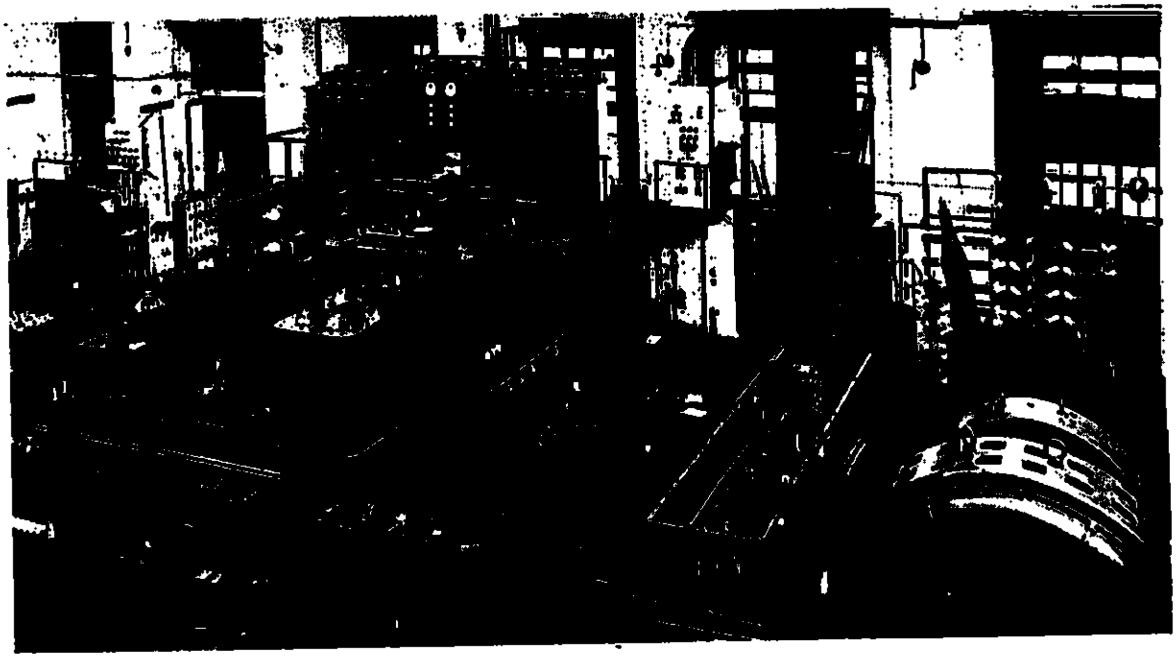
It follows from the above that E_x and E_φ can be determined for a transformer from the diagram in accordance with 2—4 when E_r and E_k are known and E_r and the efficiency at any load whatever and $\cos\varphi_2$ is determined from the diagram in accordance with fig. 5 if e.g. the copper and iron losses with $^1/_1$ load and $\cos\varphi_2 = 1.0$ are known. It follows from this that in order to know the electrical characteristics of a transformer fully (with the exception of the insulation characteristics) it is only necessary to know the value of E_k, one magnitude depending on the copper losses, and one on the iron losses (W_{cu} and W_o, or one loss figure and one efficiency figure, or two efficiency figures). The remaining electrical data can be easily obtained with the help of the above diagram and one of the simple technical calculations given. One great advantage of this is that when quoting transformers telegraphically to branches and agents it is only necessary to give three technical data figures in the telegram. A tender as complete as the customer may require, with regard to technical data, can be worked out on the basis of the telegram.

VIEWS FROM ASEA's TRANSFORMER FACTORY.

Transformers under erection for the Swedish State Railway, Stockholm—Gothenburg section, and for Finland.

A large transformer order for England under erection.

VIEWS FROM ASEA's TRANSFORMER FACTORY.



Interior of test room. Three 750 kVA single-phase transformers for New Zealand on test.

Transformers under erection for Belgium and New Zealand.

Vesteras 1925, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

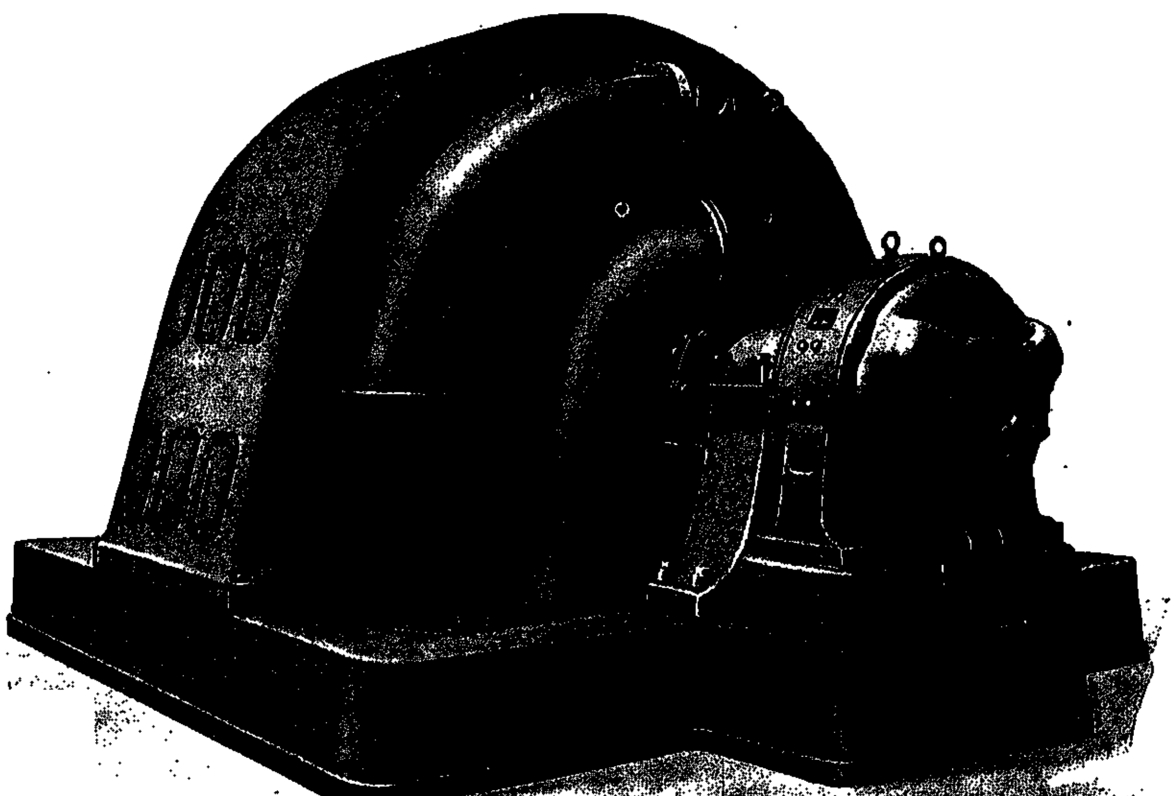
ALLMÄNNA SVENSKA
ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

VOL. III
1926

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesterås, Sweden.
Permission is given to reprint articles or extracts from this journal,
on condition that the name — Asea-Journal — is clearly stated.

FEBRUARY
No. 2



4,000 kVA self-starting synchronous motor, 750 r.p.m., 50 cycles, 5,300 volts, with direct connected exciter, delivered to Italy.

VARIOUS METHODS OF INCREASING THE EFFICIENCY OF AN INSTALLATION.

Efficiency. Power factor. Load factor.

There are a number of factors which affect the overall efficiency of an electrical plant, and which are expressed in different ways — *e.g.* ordinary efficiency = η = the relation between the power in-put and power output; the apparent efficiency = the relation between the power output and the apparent power in-put = efficiency × power factor = $\eta \times \cos\varphi$; different expressions for the degree to which the power is utilised, or the use made of the power during a certain time, such as, diversity factor and load factor, maximum and resultant factors etc. (these expressions are more closely defined in STF's Handbook XX). All such factors have the common property that the best result is obtained if they are = 1. We shall not trouble to consider the question of ordinary efficiency.

At the present time the question of power factor is one of great importance. We shall, accordingly, deal with this to some extent but our treatment will be limited to deal with power factor as affecting threephase motors and the possibility of improving it. Power can be better utilised in a number of ways, chiefly by eliminating peak loads, which can be accomplished by a number of electrical devices, regarding which a few words will be said.

Power factor of three phase motors.

It has always been known that the synchronous motor can be run with $\cos\varphi = 1$. Bearing this in mind it is interesting to remember that the synchronous motor was in existence (as a single phase motor) before the induction motor was invented. On account of the poor starting characteristics such machines were never used to any great extent, and were almost entirely eclipsed by the induction motor when this was introduced (about 1890). The induction motor was soon regarded as the ideal motor for commercial purposes and it must be acknowledged that this opinion was justifiable.

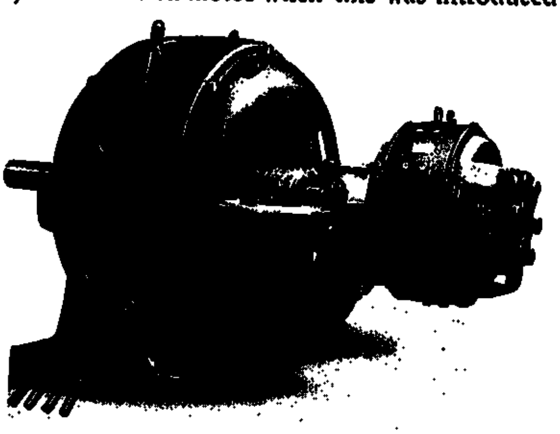


Fig. 1. Autosynchronous motor.

The fact that the power factor of the induction motor was lower than unity received considerable attention from the first. Users, however, soon learnt to accept 0.8 as a satisfactory mean value for the power factor at full load. Attempts were made, however, to increase this figure. Soon after 1895, for example, the AEG put on the market a special series of motors having a particularly high power factor, above 0.9 for all sizes, even down to about 5 h.p. This series of machines was naturally rather more expensive than the standard pattern. The good electrical characteristics of these motors were not fully appreciated by customers and the result was that this series of motors could not make headway against competition with cheaper machines and they, consequently, died out in comparatively few years.

Such an attempt having been unsuccessful it is not surprising that two inventions which attracted a great amount of attention in their day (1901) namely, Danielson's Autosynchronous Motor and Heyland's Compensated Induction Motor, were unable to obtain any footing on the market, since both these inventions involved certain complications not present in the common induction motor.

The *autosynchronous motor* (fig. 1) is now quite well known. It consists of an ordinary induction motor with slip rings and is started by means of rotor resistance in the usual way, but in addition, is provided with an exciter for supplying continuous current to the rotor windings when full speed has been attained. While running, the machine has much the same characteristics as a synchronous motor and the power factor can be varied in the same way by means of a field rheostat. The autosynchronous motor has not been utilised to the extent which might have been expected, but has, at any rate, never been altogether forgotten.

Heyland's motor was the first machine of an extensive class known as "*Compensated Induction Motors*". and may be described as an induction motor furnished with an exciter, supplying not continuous current, but three-phase alternating current of low frequency to the secondary windings. Such an exciter which, in general, consists of a commutator machine of one kind or another, can be built in a number of different ways. The problem, in this

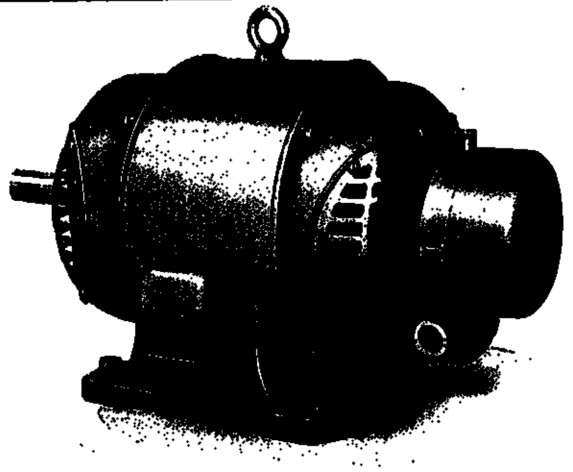


Fig. 2. Compensated induction motor.

case, is to determine a pattern of exciter, with which the advantages gained outweight the disadvantages, due to its presence.

The Heylaad motor never attained a very large field of use. It was one of those inventions, which were very much before their time. People were not ready to pay for the higher power factor obtained and the constructional difficulties were, probably, not then so well understood as they are now. The motor was forgotten for a number of years.

A compensated induction motor is very similar to an ordinary induction motor, both as regards starting and also as regards the fact that it runs with a speed which falls somewhat as the load increases, corresponding to a definite slip. It is different, however, in the important respect that its power factor is considerably higher and can be made unity at all loads. These characteristics have had the effect of bringing the machine under notice again during the last few years, during which period there has been increasing competition in the search for power factor improvement.

Asea had devoted considerable attention to this type of motor at an early date. The well-known Asea three-phase commutator motor, giving a speed regulation within wide limits, really belongs to this class of machines. If such a motor is built to run at one speed only, namely at approximately the synchronous speed instead of for variable speed it becomes very considerably simpler in construction and cheaper in first cost. A motor which has been simplified in this way is shown in fig. 2. As regards the external appearance and method of use, it is in no way different from a common induction motor. It has however embodied in the rotor an exciter winding which supplies the necessary magnetisation to maintain the power factor always = 1. Regarded theoretically this motor can be said to be an ideal machine. The success of such a motor, however, depends entirely on the reception it receives from commercial users and on the value which customers place upon the question of good power factor. It would, however, be of great interest to know if there really exists at the present time a generally felt want for such a motor.

The type referred to which can be called a "*Self exciting Induction Motor*" should be specially suitable for motors of smaller outputs up to about 100 h.p. For larger motors, particularly those running at low speeds, it is often a more practicable possibility to provide the necessary exciter as a separate machine, either driven direct or through gearing from the shaft of the main motor, or in some other manner. This arrangement is certainly the best and is the only method which can be adopted when it is desired to improve the power factor of a motor which is already installed. This possibility should always be remembered, and there are, undoubtedly numbers of cases when such a course would be both economical and advantageous.

While attempts have been made by the methods described above to improve the induction motor, it must not be forgotten that *synchronous motors* also provide means for improvement in the same direction. The common synchronous motors suffers from the disadvantage that its starting efficiency is very low in comparison with that of the induction motor. A close study of the conditions has, however, yielded valuable results as regards improvement in this respect. Asea at the present time constructs numbers of motors which are known as "*Self-Starting Synchronous Motors*". Such a motor is started in much the same manner as an induction motor with squirrel cage rotor, and differs from an ordinary synchronous motor in that special synchronising devices are not required, a very considerable advantage. A synchronous motor of this kind is shown in fig. 3.

For improvement of power factor Asea is accordingly now building simultaneously three types of motors, namely, autosynchronous motors, compensated induction motors and self-starting synchronous motors. Which of these three types is to be preferred must in every case depend on the actual conditions. Each of the three possesses certain qualities which render it, more or less, suitable for certain classes of work. Closer investigation of this point would occupy too much space here. It is, however, clear from what we have stated that any customer wishing to install a motor, the power factor of which will be unity under all conditions, can always realise this desire no matter what the machine is to drive. This applies to motors intended for both continuous and intermittent

work, with constant and variable load and at constant or variable speed.

All of the motor types referred to which can be designed for unity power factor can also, as a further step, be constructed so as to deliver reactive power, and thereby indirectly raise the overall power factor of the plant installed. This is brought about by over-magnetisation — *i.e.* such an arrangement of the exciter that it supplies more current than corresponds to the reactive current required by the machine itself. We thus have a method of raising power factor, which, although known and appreciated for some considerable time, still warrants the greatest attention, even to-day. The common synchronous motor and also the autosynchronous motor under certain conditions should be mentioned as being particularly suitable for this purpose.

Electrical Methods for steadying Fluctuating Loads.

Any source of power can be utilised in the best way which has so far been discovered by electrical transmission and distribution. This applies both to possibilities of selling the available energy at a profit, and also to the means which are made available for regulating the available and the consumed energy. Nevertheless, the last named question involves a number of problems which have not so far been solved. These chiefly concern the balancing of power requirements against the power available at any time, and the utilisation of excess power. The efficiency of any installation in this respect is in general very far from the desired 100 %.

A means of increasing this efficiency lies to a great extent in making the load continuous and invariable. We must accordingly refer briefly to the various means adopted for this end. In general a distinction can be made between two entirely different methods, viz. the storage of energy and the smoothing out of load fluctuations.

Storage.

Regarding storage, we must naturally first consider the direct electrical or electro-chemical method, *i.e.* the accumulator battery. This method has, however, only been used to quite an insignificant extent commercially. The reasons for this, viz. high cost and low efficiency, particularly in cases where power is generated and used in the form of AC, are well known. The need of a really good accumulator is an exceedingly pressing one in these days. In spite of this it must unfortunately be stated that progress in this direction during the past thirty years has hardly advanced by a single step in comparison with the developments which have been made in other branches of electro-technics.

Fig. 3. Self-starting synchronous motor.

It may often be wondered if the existence of the accumulator has not been entirely forgotten in many branches of engineering.

A method which has been known and utilised for a long time is the conversion of electrical energy into rotational energy which is stored in a flywheel, and this method has been widely used for motors driving intermittent loads. The most common arrangement is to connect the flywheel directly to the motor, as is usual, for example, with three-phase rolling mill motors, or to connect a regulating set furnished with a flywheel between the main motor and the supply. An exemple of this is the use of an Ilgner set for colliery winders or reversing rolling mills. In contrast to the use of such, what may be called, individual flywheels (one for each motor), it is often possible to make use of one flywheel for a number of motors by having the flywheel connected to a machine which runs otherwise unloaded, and works alternately as a motor or generator. We are fully aware that this method has not been used to any great extent, but at the same time it is well worth consideration. Under certain conditions it can be particularly effective when it is desired to smooth out load peaks and to reduce the variations of voltage and frequency dependent on them.

In the case of the two methods of storage described above, electrical energy is changed into some other form and afterwards re-converted and utilised again as electrical energy. In other methods it is possible to work with one transformation only. Such a method is electric heat storage. This can be carried out in many different ways. Energy can be utilised in heating water, which can be used for the warming of buildings or as feed water for steam boilers. It is also possible to take a step further and

to generate steam which can be fed into a steam accumulator. Further, energy can be stored in cooking stoves or ovens for heating of buidings. Valuable possibilities exist in this direction for storing electrical energy, although these methods have so far been very little made use of.

There is another kind of accumulating effect which is quite different from the process described. In this case excess power is used for the production of a half finished product, which is placed in storage when the supply of energy fails, the production being again started when the next period of excess power occurs. An interesting example of this is to be found in the attempts which have recently been made to make use of excess power in wood pulp mills. The half finished product consists of raw mechanical wood pulp which is placed in suitable containers for storage. The technical efficiency of such a storage method is exceedingly high, since the losses occurring are due only to the power which* must be supplied to the pumps for raising the raw pulp from the containers. The economic efficiency naturally depends on the local conditions and the possibility of arranging storage containers in a cheap manner. However, as 1 cu. m. of wood pulp represents 50 to 75 kWh, the necessary volume is not great. (A container corresponding to a 10 m cube will represent 50,000 to 75,000 kWh).

Regulation of Power Consumption.

An installation of the kind last referred to can also be used to regulate the power used, since it can be started and stopped at will, and the power absorbed can be varied within wide limits. This also applies to the other methods of storage which we have dealt with, with the exception of flywheel methods.

At the same time there are relatively few possibilities for regulating power alone, without at the same time making use of storage. Most industrial processes require the greatest possible continuity in order to give the best economical result. The possibility of effecting regulation electrically exists, however, in such cases where the excess power can be used instead of some other existing source which can, without disadvantage, be closed down.

An example of this is the arrangement of an electric steam boiler working in parallel with a boiler fired with coal or other fuel, which experience has shown to be, under certain conditions, a particularly economical combination.

In a similar manner electric energy can also be made use of for drying ovens working with heated air. Perhaps the power required in this case is, generally, small in comparison with the normal output of a modern supply system, but, nevertheless, this method can be of considerable importance for the isolated user when effective utilisation of the power which has to be paid for is under consideration. (As an example, the Asea works at Vesteras use 700 to 800 kW for such drying ovens, and this corresponds to practically half of the power which is used for running motors).

For obtaining power regulation over long periods of time, electrochemical and electrometallurgical furnaces are also of great importance. It may be mentioned that normally an electric furnace for the production of pig iron requires approximately 3,000 to 6,000 kW.

Parallel Running.

The methods described above for steadying fluctuating loads can in general be applied to any power supply. It is clear that possibilities of making use of them can be increased to a great extent by parallel working. The advantages of parallel operation between large supply systems can hardly be over-estimated with respect to improving the overall efficiency. If, at the same time, we take into consideration the saving in water power (in the case of hydro-electric installations) which can in general be effected in this way, it is not to be wondered at that this matter of parallel operation has become one of the greatest questions of the day.

Regarding parallel running, it is as well to mention that power supplies of different frequency can now be connected up without difficulty by making use of frequency converters. Such frequency converters can be so designed that they are completely reversible, and power can be transferred at will from one system to the other, or they can be arranged so that a constant amount of power is automatically transferred continuously from one system to the other.

Finally, it may be remembered that all regulation, both of power factor and of power used, can be simplified to a great degree by the use of automatic devices. During the last few years a great amount of work has been done by Asea in the perfection of relays and automatic switches of various kinds which have been found to be required for the solution of the various problems which have occurred.

It has always been, and still is usual, to check the efficiency of electric generators with pedantic accuracy. In spite of this it is also just as usual to neglect almost entirely the question of plant running efficiency and load factor. This is of the nature of straining at a gnat and swallowing a camel, which has always been recognized as rather absurd.

THREE-PHASE SQUIRREL CAGE MOTORS WITH HIGH STARTING TORQUE.

The three-phase squirrel cage motor is the best example extant of an electrical machine as regards dependability and simplicity. It has no commutator or sliprings, no brushes and no moving contacts, and the rotating winding is of the simplest and mechanically strongest design.

The fact that the use of the squirrel cage motor has not out-distanced other types on the market is chiefly due to the fact that the starting torque of a machine of this kind is relatively low in comparison with the starting current (low cos φ during starting). In attempting to improve the starting characteristics it is necessary to investigate the conditions during the starting of a slipring motor provided with a rotor starter. In this case the secondary resistance is high at the instant of switching on, and is decreased by operating the starter handle as the motor increases in speed. A number of methods have been tried in order to modify the squirrel cage motor in this respect, *e.g.* by using a centrifugal switch on the rotor, which, on operating, short circuits or disconnects a separate resistance contained in the rotor, or else alters the winding itself by means of reconnection. The introduction of such contacts, however, means more or less a departure from the simplicity and hardiness which we commenced by pointing out as being the advantage of the squirrel cage machine.

Another means of overcoming the difficulty is to make use of what is known as the "skin effect" of AC, which causes an increase in the effective resistance of a winding. This increase depends on the applied frequency, so that in a squirrel cage rotor suitably designed to make use of skin effect, the resistance is high at standstill when the rotor current is at the full supply frequency, and is decreased as the speed rises and the frequency of the rotor current falls off. This has the appearance of being an ideal solution, but unfortunately a design that gives the desired skin effect will necessarily be found unfavourable as regards maximum torque and power factor under normal running conditions, since the magnetic leakage in the rotor is greatly increased. The construction adopted has therefore to be a compromise between starting and running requirements.

The required increase in resistance due to skin effect can be obtained by making the rotor conductors of considerable radial depth. Thus we have to proceed in exactly the opposite way to that which is normally adopted for overcoming skin effect, *e.g.* in the stator windings of AC machines. An investigation shows, however, that by using deep conductors with plain parallel sides, the effective resistance and leakage reactance so introduced are dependent upon one another in a way which does not allow a suitable choice of the relation between the two values.

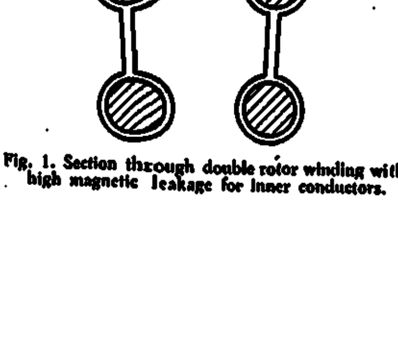


Fig. 1. Section through double rotor winding with high magnetic leakage for inner conductors.

If, instead of the above, we use two circular conductors, one above the other in the same slot, and if the slot is made particularly narrow between the conductors, as shown in fig. 1, it is possible to vary the resistance and leakage between wide limits. The two rows of conductors in all slots are on opposite sides connected by separate or common short circuiting rings. This winding was first suggested by Boucherot.

We shall now indicate briefly, and in a mathematical manner, what result can be obtained with such a double rotor winding. All voltages, currents and resistance values are calculated *per phase*, and the secondary values are recalculated to correspond to the number of turns in the primary winding. All reactances are calculated from actual leakage but at full primary frequency. The following symbols are employed:

m = number of phases.
E = stator terminal voltage.
I = stator current.
r_1 = stator resistance.
r_y = resistance of outer rotor winding.
r_i = resistance of inner rotor winding.
x = r_i/r_y.
r_p = resistance of the two rotor windings in parallel = $\frac{r_y \cdot r_i}{r_y + r_i}$
x_1 = leakage reactance of stator.
x_{2g} = that part of the rotor leakage reactance resulting from the common leakage field of the two rotor windings.
x_{ye} = that part of the leakage reactance of the outer rotor winding, resulting from its individual leakage field, (*e.g.* round the short circuiting rings).
x_{ie} = that part of the leakage reactance of the inner rotor winding resulting from the individual leakage field, chiefly through the waist of the slots.
$X_g = x_1 + x_{2g}$.
ξ = the relative increase of total leakage reactance during running caused by x_{ie}.
s = the slip.

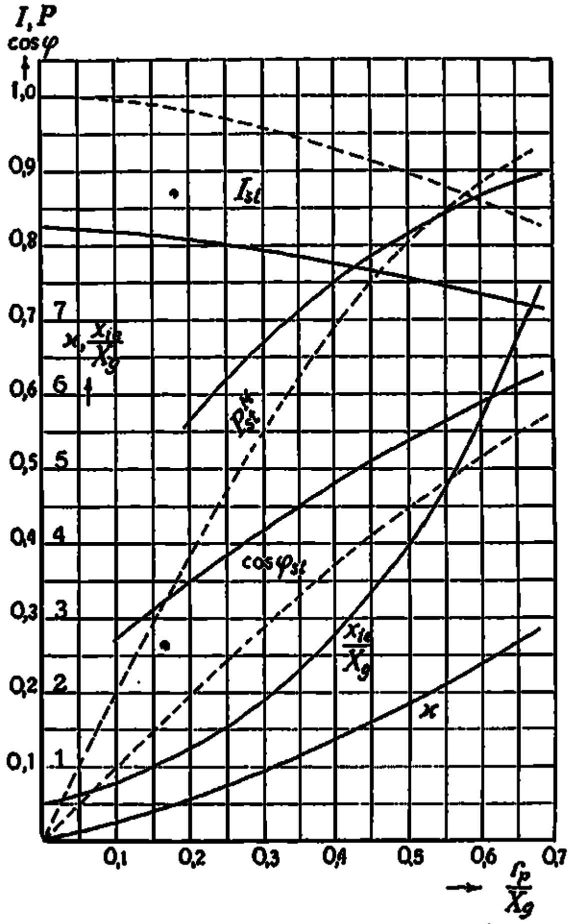


Fig. 2. Curves for best proportions of rotor windings on the assumption that the total leakage reactance of the motor can be increased by 50 % ($\mathring{s} = 0.5$). The starting current (I_{st}), starting torque (P_{st}^{M}) and power factor at start ($\cos \varphi_{st}$) are drawn both for the motor in question (full lines), and for normal motor (dotted lines). As regards units for I_{st} and P_{st}^{M}, see text.

Further, used as suffixes, letters y and i refer to the outer and inner rotor windings, and figures 1 and 2 primary values and resulting secondary values at standstill respectivly.

Total Resistance and Reactance of the Rotor.

On starting, if L-values are the inductances corresponding to the abovenamed x-quantities, we have for the outer rotor winding,

$$r_y I_y + j\omega L_{2g} (I_y + I_i) + j\omega L_{ye} I_y = E_{ind}$$

and for the inner winding

$$r_i I_i + j\omega L_{2g} (I_y + I_i) + j\omega L_{ie} I_i = E_{ind}$$

or, if ωL is replaced by x,

$$r_y I_y + jx_{2g} (I_y + I_i) + jx_{ye} I_y = E_{ind} \ldots (1)$$

$$r_i I_i + jx_{2g} (I_y + I_i) + jx_{ie} I_i = E_{ind} \ldots (2)$$

The equivalent impedance components for a simple rotor winding we may call r_2 and x_2 and put

$$x_2 = x_{2g} + \Delta x \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Then we also have the equation

$$r_2 I_2 + jx_{2g} I_2 + j \Delta x I_2 = E_{ind} \quad \ldots\ldots (4)$$

where $I_2 = I_y + I_i$

Equations (1), (2) and (4) give us

$$r_2 = \frac{r_y r_i (r_y + r_i) + r_y x_{ie}^2 + r_i x_{ye}^2}{(r_y + r_i)^2 + (x_{ye} + x_{ie})^2}$$

$$x_2 = x_{2g} + \Delta x = x_{2g} + \frac{r_y^2 x_{ie} + r_i^2 x_{ye} + x_{ye} x_{ie} (x_{ye} + x_{ie})}{(r_y + r_i)^2 + (x_{ye} + x_{ie})^2}$$

Examination shows that x_{ye} decreases r_2. It can also be seen that x_2 is increased at any rate in certain cases. The effect of x_{ye} is thus of no advantage, and this quantity should accordingly be made as low as possible by suitable dimensioning and location of the short circuiting rings. If x_{ye} disappears, our formulae, using the symbols:

$$\varkappa = \frac{r_i}{r_y}$$

and

$$r_p = \frac{r_y r_i}{r_y + r_i}$$

can be simplified to

$$r_2 = r_p \cdot \frac{1 + \frac{\varkappa}{(1+\varkappa)^3} \left(\frac{x_{ie}}{r_p}\right)^2}{1 + \frac{\varkappa^2}{(1+\varkappa)^4} \left(\frac{x_{ie}}{r_p}\right)^2} \ldots (5)$$

$$x_2 = x_{2g} + x_{ie} \cdot \frac{\frac{1}{(1+\varkappa)^2}}{1 + \frac{\varkappa^2}{(1+\varkappa)^4} \left(\frac{x_{ie}}{r_p}\right)^2} \quad (6)$$

With these values of r_2 and x_2 the starting characteristics of the motor can be calculated in the usual manner.

In the neighbourhood of synchronism, it is clear that since x_{ie} is replaced by $s \cdot x_{ie}$ and s approaches 0, we can write

$$r_{2\,(s=0)} = r_p \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

The actual secondary reactance is now

$$sx_{2g} + sx_{ie} \cdot \frac{1}{(1+\varkappa)^2}$$

and reduced to primary frequency

$$x_{2\,(s=0)} = x_{2g} + \frac{x_{ie}}{(1+\varkappa)^2} \quad \ldots\ldots (8)$$

Consideration of Power Factor during running and Overload Characteristics.

The effect of the special winding arrangement on the running characteristics of the motor is, so to speak, latently expressed in equations (7) and (8). Power factor and overload capacity are both made worse in comparison with those of a normally constructed motor, due to the increase in reactance. The total reactance with a small slip is

$$X_{(s=0)} = X_s + \frac{x_{ie}}{(1+\varkappa)^2}$$

It should be remembered that $X_{(s=0)}$ lies very

close to the actual running value, while the slip corresponding to M_{max} is so great that the value of X can here be considerably lower.

If we determine that the increase of X_g is not to exceed a certain percentage so that

$$X_{(s=0)} \leqq (1 + \xi) \cdot X_g \;\ldots\ldots\ldots\; (9)$$

we obtain as a maximum

$$x_{le} = X_g \cdot \xi\,(1 + \varkappa)^2 \;\ldots\ldots\ldots\; (10)$$

The best Resistance Proportions for the Rotor.

We must now determine the most suitable values of $\varkappa$ with any chosen value of ξ. By most suitable value we mean that which gives the greatest starting torque in relation to the starting current, *i.e.* the highest power factor at starting. If in determining this maximum value we disregard the action of the magnetising current at starting and also the primary resistance, which is allowable as the maximum is not very marked, we can put

$$\tan \varphi_{st} = \frac{x_1 + x_2}{r_2}$$

which, with the help of equations (5), (6) and (10) gives

$$\tan \varphi_{st} = \frac{X_g}{r_p} \cdot \frac{1 + \xi + \xi^2 \varkappa^2 \left(\frac{X_g}{r_p}\right)^2}{1 + \xi^2 \varkappa\,(1+\varkappa)\left(\frac{X_g}{r_p}\right)^2} \quad (11)$$

If this equation is differentiated with respect to $\varkappa$ and equated to zero, we obtain that value of $\varkappa$ which gives the least $\tan \varphi_{st}$ and accordingly the greatest $\cos \varphi_{st}$ with the values of X_g/r_p and ξ in question. We then obtain

$$\varkappa_{(\varphi_{st}=\min)} = \frac{1 + \sqrt{1 + (1+\xi)\left(\frac{X_g}{r_p}\right)^2}}{\xi\left(\frac{X_g}{r_p}\right)^2} \;\ldots\ldots\; (12)$$

From this we also find how the quantity of copper corresponding to r_p should be divided between the inner and outer conductors. We can, for example, construct a curve giving the best values of $\varkappa$ as a function of r_p/X_g for a given value of ξ. This is done in fig. 2 for $\xi = 0.5$. The value of X_g is generally fixed by the size of the motor, number of poles, air gap etc., and r_p must be chosen with regard to the temperature rise and efficiency. Thus, r_p/X_g is determined from the beginning; it should naturally be kept as large as possible.

The fact that ξ has been chosen $= 0.5$ signifies that the original total reactance is increased by 50 %. After the introduction of the special rotor winding the original power factor of *e.g.* 0.9 at full load is reduced to about 0.86, provided that no special alteration for improving it has been made at the same time, by increasing the number of slots or otherwise. From the curve in fig. 2 we can immediately find for this value of ξ the best proportion between the cross sectional area of outer and inner conductors (if both are of the same material).

The value of x_{le}/X_g is then obtained from equation (10). This is also shown in fig. 2. From this value we can in the ordinary way calculate the relation between the depth and width of the waist of the slot, fig. 1. The dimensions of the rotor winding are thus fully determined; it only remains to settle less important matters of detail. The short circuiting rings for the outer row of conductors should be made with the least leakage. If their resistance is noticeable by comparison with that of the conductors themselves, this can be easily corrected.

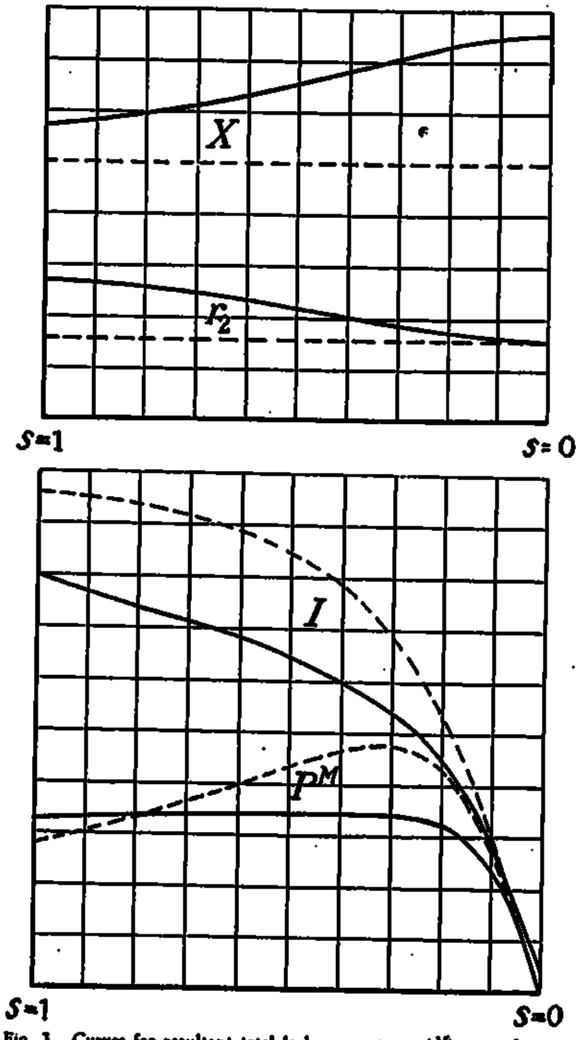


Fig. 3. Curves for resultant total leakage reactance (X), secondary resistance (r_2), primary current (I) and torque (PM), all as functions of the speed or slip of the motor being started at any instant. The full line curves refer to motor dimensioned in accordance with fig. 2. The dotted lines refer to normal motor with the same total cross sectional area of copper in the rotor. For data etc. of motor, see text.

It is worthy of note that the best value of $\varkappa$ often is > 1, the inner conductors thus being the smaller, and this is so to a greater extent the larger we choose r_p. We might otherwise have thought that the cross sectional area of the inner conductor should be chosen particularly large, and that of the outer conductor particularly small, so as to obtain a high secondary resistance at starting. In this case, however, during normal running when the rotor current is divided fairly evenly over the whole cross section, a large part of the current would pass through the inner conductor which has high leakage,* and ξ would become exceedingly great and cos φ during running much too low. *This indicates a definite limitation for motors employing this method of starting.*

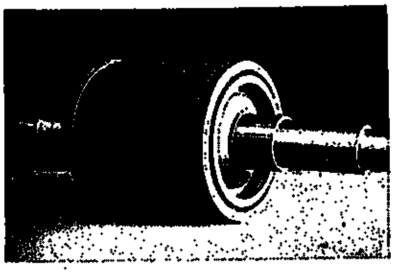


Fig. 4. Rotor with two squirrel cage windings, for motor of 10 h.p., 1,500 r.p.m.

Starting Current and Starting Torque.

Using the same approximations as before, the starting current is given by the expression

$$I_{st} = \frac{E}{\sqrt{(x_1 + x_2)^2 + r_2^2}} \;\ldots\ldots\; (13)$$

which, with the help of equations (5), (6), (10), and (12), can be expressed as a function of ξ, r_p/X_g and E/X_g. In fig. 2 I_{st} is drawn for $\xi = 0.5$ with E/X_g as a unit. Taking the no load current and primary resistance into consideration, I_{st} can easily be obtained graphically, or alternatively the value of the curve can be corrected by a suitable factor, *e.g.*

$$k = \frac{1}{1 + \frac{x_1}{2X_0} + \frac{r_1 r_2}{r_2^2 + (x_1 + x_2)^2}} \;\ldots\ldots\; (14)$$

where X_0 denotes the relation between the induced voltage and the magnetising current.

The starting torque expressed, as power at synchronous speed, ("torque power") P^M_{st}, is calculated in analogy with the starting current as

$$P^M_{st} = m\,E\,I_{st} \cos \varphi_{st} = m\,E^2 \frac{r_2}{(x_1 + x_2)^2 + r_2^2} \;(15)$$

(m = number of phases) which is indicated in fig. 2 with $\frac{mE^2}{2X_g}$ as a unit. The correction factor is the square of the correction factor for I_{st}, *i.e.* k^2. See equation (14).

The power factor is indicated in fig. 2 as

$$\cos \varphi_{st} = \frac{r_2}{\sqrt{(x_1 + x_2)^2 + r_2^2}} \;\ldots\; (16)$$

The correction factor is naturally the same as for I_{st}, *i.e.* k in accordance with equation (14).

Torque and Current during Acceleration Period. Maximum Torque.

From equations (5) and (6), r_2 and x_2 can be calculated for different current frequencies in the rotor, *i.e.* for different values of slip. As an example a motor has been calculated out having $r_p/X_g = 0.315$, $\xi = 0.5$ thus giving the best value of $\varkappa = 1$ and $x_{le}/X_g = 2$. Further, it has been assumed $X_0/X_g = 20$, $x_1/X_g = 0.6$ and $r_1 = 0$. Fig. 3 shows the result obtained as a function of s, together with corresponding curves for a normal motor with $x_{le} = 0$, but otherwise the same. The curve of torque has been, practically speaking, levelled out; the actual advantage lies in the decreased current. By choosing the dimensions of the windings and slots in a somewhat different manner, we can obtain a torque curve which is actually inclined downwards right from the standstill ($s = 1$). Such a motor will not fall "out of step" if the load is too great as in the case of an ordinary three-phase motor, but will gradually decrease in speed, picking up again when the load falls off. In spite of a higher price such a motor is to be recommended in certain cases, as it permits a complete recovery of all energy stored in rotating masses, without at the same time giving rise to a weakened torque, which would make reacceleration impossible.

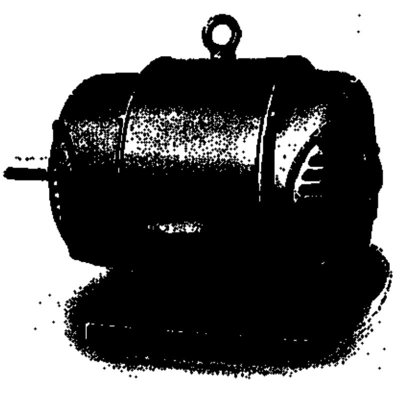


Fig. 5. External view of motor for 10 h.p., 1,500 r.p.m.

In cases, where the torque curve shows a marked peak for $s < 1$, the maximum torque can be calculated in the following way. The slip corresponding to this value is first taken to be

$$s_{(M = \max)} \approx \frac{r_p}{X_g\,(1 + \xi)}$$

Afterwards r_2 and x_2 are calculated from equations (5) and (6) with x_{le} in equation (5) and in the denominator in equation (6) substituted

by $x_{ie} \cdot s_{(M=max)}$. A new corrected s-value is calculated with the values of r_2 and x_2 so obtained.

$$s_{corr} = \frac{r_2}{x_1 + x_2}$$

and with this s-value r_2 and x_2 can be further corrected. Lastly, P^M_{max} can be calculated in the usual manner, *e.g.*

$$P^M_{max} = \frac{m\ E^2}{2X} \cdot \frac{1}{\left(1+\frac{x_1}{\sqrt{2}\,X_0}+\frac{r_1}{2\,(x_1+x_2)}\right)^2} \quad (17)$$

where m = the number of phases and X_0 = induced voltage : the magnetising current. It makes the matter clearer to draw part of the curve $P^M = f(s)$ so that the maximum value can be read off direct.

Conclusion.

For a relatively small increase in price it is possible by the use of the double rotor winding described to improve the starting characteristics of the squirrel cage motor within certain limits. Generally speaking, it should be possible by making use of Y/Δ-starting, to expect a starting torque of 75 % with a starting current of 150 %, provided that the speed is not too low. In particularly favourable cases better results can be obtained. A slight disadvantage of the motor is that the power factor during actual running is somewhat worse. In cases where power factor correction is effected by one or more large synchronous machines this condition is of much less importance. A further point to be noted is that the maximum torque of the motor is somewhat reduced. It should be remembered, however, that the ordinary squirrel cage motor has in general such a high maximum torque that a part of this can usually be sacrificed without endangering satisfactory running. And, as already pointed out, the special shape of the torque-slip curve attained lessens the danger of the motor's falling "out of step". What is not affected to any degree, and still represents a big advantage with this type of motor, is the reliability and insignificant attention required.

Figs 4 and 5 show a motor of the type described, for an output of 10 h.p. at 1,500 r.p.m.

TRANSFORMERS FOR RURAL ELECTRIFICATIONS.

The characteristics which denote a good transformer are covered, with a few exceptions, by the requirements of good economical working. Economy in a transformer means that the cost of transformation of the electrical energy must be low. This cost is made up of capital charges and depreciation, cost of repairs and maintenance, and the cost of the energy absorbed by the transformer losses. To keep the maintenance costs low the transformer should be highly reliable and this, according to experience, denotes that the transformer must be able to withstand the electrical and mechanical stresses arising in normal working without any damage, and deal with the electrical load without any of its parts reaching a dangerously high temperature. As the choice of the best transformer is clearly a purely economical problem, excessive attention to any of the separate details will adversely affect the economical result which is sought as a whole.

It may be uneconomical to insulate a transformer so that it can withstand all excessive pressures, as for example, those occurring with a direct lightning stroke on the line in the neighbourhood of the transformer, if thereby the increased cost and the increase in the losses, inseparable from the strengthened construction, exceeds the repair costs. On the other hand it may be uneconomical to alter the construction so as to obtain cheap first cost and low transformer losses so much as to lower the reliability, and thereby increase the repair and maintenance charges. Since, as in most technical problems, we have to consider a number of partly unknown factors, it follows that a definite single solution cannot be given. By compromising between the various factors found by experience it is, however, often possible to come fairly close to the correct solution. The idea of the present article is to present a number of points which are drawn from the experience of Asea regarding the choice of transformers for rural electrifications which have a direct influence on the economy of such schemes.

Transformers for rural supply purposes are commonly installed in a manner which is considerably different from that adopted with transformers for industrial use. Compared with the size and number of the transformers the length of supply line on the high tension side is very considerable. The connections to the low tension side also usually consist of overhead lines of considerable extent. These low tension lines, and the installations to which they are connected, are often carried out in a rather unsatisfactory and unworkmanlike manner. It follows from the above that distribution trans-

formers for country installations must be designed for various disturbances, arising especially from atmospheric sources, lightning etc. and also from short circuits in the installations connected to the low tension side.

On these distribution schemes properly trained personnel as well as shops for repairing transformers are often lacking. This means that repairs are costly, as expensive carriage charges or travelling expenses of erectors are inseparable from them while a repair is always in any case a special job. Repair work is accordingly of necessity expensive. It is no exaggeration to say that the average cost of a repair is about equal to half the price of a new transformer. In this connection we have not attempted to estimate the cost of the inconvenience which follows on a cessation in the supply, and which in certain circumstances can be particularly serious.

In the Swedish Standardisation Rules certain minimum requirements regarding strength of insulation between windings, and between windings and iron, and between turns are specified, or at least recommended. The question at once arises: are these specified requirements sufficiently severe to ensure economical reliability on transformers for rural electrifications? Investigations on a number of distribution transformers, designed for working voltages on the high tension side from 1.6 to 10 kV, which were repaired by Asea during the years 1920—1921 have provided some interesting results.

In 90 % of the transformers, the high tension winding was found to be damaged by short-circuits between turns.

In 21 % of the transformers, short-circuits in the lowtension windings had developed. In 75 % of these the shortcircuits were only in the low tension winding, whereas the others had faults in both windings.

In 17 % of the transformers the faults seemed to indicate flash-overs from the high tension winding to the low tension winding or to the iron. At least half of these apparent break-downs, however, were probably caused by burns from short-circuits in the windings. Of those cases, where the flash-overs seemed to have been the primary cause of the faults, 90 % had the high tension winding wound directly on the low tension winding with an intermediate insulating cylinder.

In 2 % of the cases flash-overs from the low tension winding to the core had occurred, probably during thunder-storms.

Finally 1 % of the faults were caused by continued overload with the result that all the insulation was completely carbonized.

An examination of the figures obtained shows without any doubt that the greatest weakness of the faulty transformers lay in the insulation between turns. This was in 98 % of the cases carried out with paper used during the war owing to lack of cotton. The short circuits were, however, evenly divided over the whole winding, and not confined to the coils near the terminals at the ends of the winding. In many cases short circuits had occurred in the high tension coils at the inner side close to the low tension winding, and appeared to have occurred as a result of the non-provision of an oil duct between the two windings.

In order further to investigate the power of resistance of small transformers to strains of various kinds, several years ago a number of tests were carried out on 10 transformers of 25 and 50 kVA, 12,000 volts manufactured in 1920. The tests included switching on and off at full voltage a number of times with an oil switch not provided with charging resistance, excess voltage and over-magnetisation tests, wave front tests by connecting and disconnecting a condenser, and short circuit tests. The result of these tests showed that the insulation between windings and to iron and between turns was particularly strong. Over-magnetisation and condenser discharge up to 80 kV did not cause any defects to develop. On short circuit, however, a number of weaknesses were discovered. The power behind the transformers was 800 kVA. Among

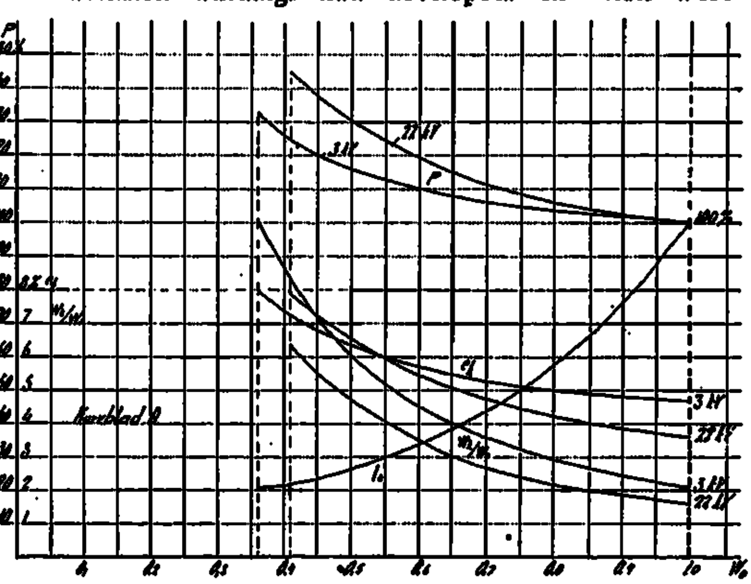


Fig. 1. Curve A.

other things it was shown that the coils and insulating material had not sufficient mechanical stability to withstand the mechanical stresses arising on short circuit without damage. In a number of cases, after 50 short circuits, the high tension windings were found to be exceedingly loose on the cores; the coils had twisted etc. It appeared certain accordingly that the greater percentage of short circuits between turns on the high tension windings of transformers repaired by us is to be ascribed more to the lack of mechanical stability in the coils and mechanical tensile stress in the paper insulation used, than in low insulation strength between turns.

Making use of the information thus obtained it appears that specifications for distribution transformers should, in addition to the usual standardisation requirements, combine a number of extra regulations approximately in accordance with the following:

All insulating material used should be mechanically hard and compact and should not shrink too much under pressure.

All coils should be mechanically compact and stable. This is most simply obtained in a satisfactory manner by vacuum impregnation of the finished coils with oil resisting varnish or compound.

The mechanical construction of the windings, insulation and winding clamps should be such that the maximum of safety is obtained on short circuit. Even if short circuit tests cannot be conducted in the test room, an investigation of the construction and design should be carried out to see whether the guaranteed safety against short circuit is present or not.

The insulation between the high tension winding, on one side, and the low tension winding and iron, on the other side, should be such that brush discharge does not occur with excess voltages of short duration, of a magnitude for instance, equal to the flash-over voltage of the leading through bushings according to the Swedish Rules. Even if a flash-over or a breakdown does not occur, brush discharge can, in a short time, greatly damage the insulation between turns so that a short circuit will follow. Vacuum impregnation of the coils decreases the danger of short circuit between turns caused by brush discharge at the surface of the coils. From this it follows that an arrangement with the high tension winding wound directly on the low tension winding without an oil duct is not satisfactory, unless a very heavy insulating cylinder be placed between the windings.

The load conditions of transformers for rural electrification are not less peculiar than the conditions of installation. A transformer for this work is chosen with regard to the maximum load which often only occurs during a few weeks in the year; during the rest of the year the transformer works, practically speaking, on no load. It follows from this that during a great part of the year the energy supplied to the transformer is dissipated in the form of no-load losses. Cases exist where the no-load losses of a distribution scheme reach, during the year, a larger value than the actual useful energy supplied. With special regard to this fact most firms have on the market a special series of transformers designed with smaller no load losses and larger copper losses than the usual standard. These commonly cost rather more, but are considerably more economical to the buyer on account of the decreased energy supplied for iron losses. At the same time a decrease in no-load losses must not be purchased at the expense of reliability on the part of the transformer.

The requirement of great reliability involves, among other things as stated above, that no parts of the transformer shall in working reach a dangerously high temperature. In order to make certain of such reliability the Swedish Rules require that with continuous service with an output as shown on the transformer data plate, the temperature rise in the hottest part of the oil shall not exceed that of the cooling medium by more than 60° (under certain conditions 55°), and further that the temperature rise of the windings determined by increase of

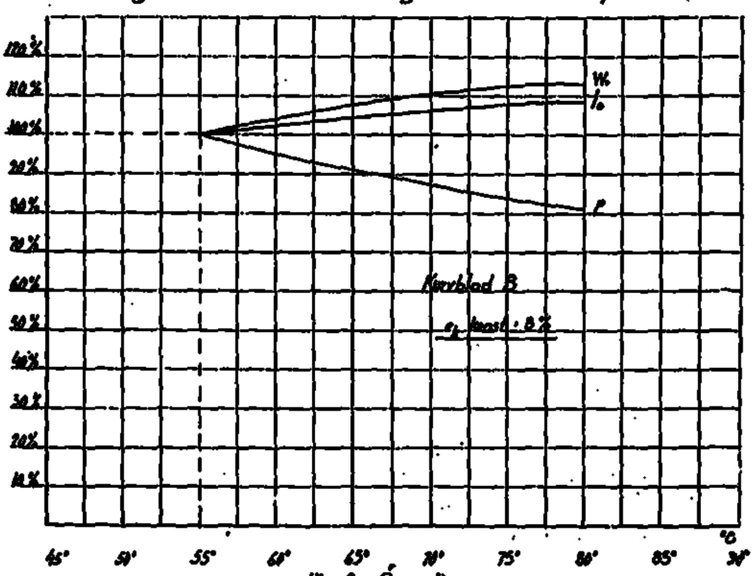


Fig. 2. Curve B.

resistance shall not exceed the temperature of the cooling medium by more than 60°. The cooling medium is here assumed to have a temperature not exceeding 35°. On carefully investigating what is implied by these requirements we find that a highest temperature in the hottest part of the windings of about 110° is not considered detrimental to the transformer, even on continuous load.

The effect of temperature on an insulating material of organic nature such as paper or cotton, manifests itself chiefly in a lowering of the mechanical strength. The electrical breakdown strength is maintained practically unaffected until carbonisation begins. The effect of heating, besides being dependent on the actual temperature, depends greatly on the time for which the heating endures. For cotton and paper immersed in oil the following roughly approximate table may be used to assist in determining the effect of temperature; the table gives the time taken to damage insulating material to the same extent with various temperatures.

Table.

Temperature: °C	110	120	130	140	150
Time in hours.	100,000	10,000	1,000	100	10

A temperature below 80 to 90° has, practically speaking, no effect on insulating material immersed in oil or protected in some other way from the action of air.

Transformers for the service under consideration have commonly been chosen with a capacity at least corresponding to the greatest motor load which will be thrown upon them, and this capacity determined with regard to the temperature rise allowed by the Swedish Rules. Such a transformer is unnecessarily large. A transformer which is too big means an unnecessarily high first cost and above all no load losses which are unnecessarily high. A proper selection of the size of a transformer is most certainly one of the most important ways of reducing the no load losses on a distribution scheme.

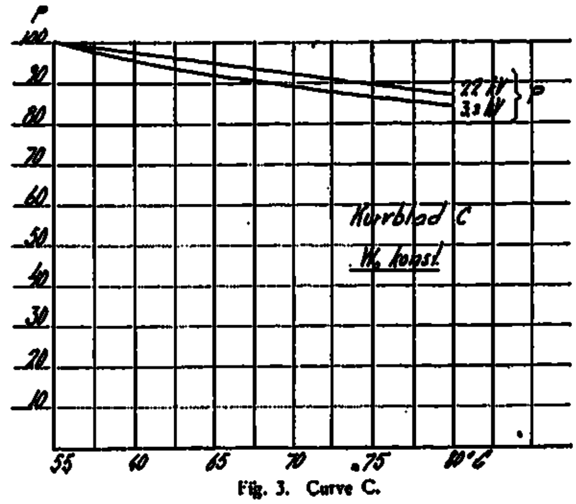


Fig. 3. Curve C.

A transformer of the type and size in question requires a time of from 12 to 15 hours to reach a constant temperature with a certain constant load. A motor of corresponding size reaches a constant temperature in from 2 to 3 hours if of the open type, and if enclosed in 6 to 7 hours. A normal working day seldom exceeds 10 hours, including a lunch pause. Before and after use on such a working day the transformer runs practically unloaded. It is clear that, on account of the very limited time which the greatest load is on, a transformer dimensioned in the manner referred to above never reaches the temperature rise which is allowable.

Further, the number of days in the year which a transformer subjected to an agricultural load runs fully loaded are very few. 14 days full load running per year is not uncommon. To be quite safe we can reckon on 50 days. With regard to the heat capacity of the transformer just referred to, it will be seen that the temperature only reaches such a value as to have any effect on the life of the transformer during a very small part of the day. An assumption that a daily load corresponds to two hours' running with the highest temperature is still considerably on the safe side. During the remainder of the year the load can be neglected, as the temperature reached lies under the limit at which any action on the insulating material is brought about. A year accordingly corresponds, with the assumptions just made, to 100 hours' working with the maximum temperature reached. Taking a life of 20 years, which is by no means too short a time, the maximum temperature reached should be chosen to correspond to an action of 2,000 hours, which in accordance with the approximate table given above corresponds to about 128°, or 18° above the temperature allowed by the Rules.

Lastly, the Rules for limiting temperature rise start from the assumption that the cooling medium (that is to say, in rural distribution work, the air) does not exceed a temperature of 35°. On an electrified farm the greatest load takes place when threshing is being done, and this comes at a time of year when the temperature of the air at the conclusion of a working day cannot possibly reach 35° C. 20° would be a much more correct value. As it is the highest temperature existing in a transformer which is limited, it follows that a reduction in the assumed temperature of the windings makes possible a corresponding increase in the temperature rise, *i.e.* the transformer can be more heavily loaded.

If attention is paid to the heat capacity of transformers of the agricultural type, to the shortness of the maximum loads, and the low air temperature when the maximum loads occur, it is found that the transformer chosen for the greatest motor load in accordance with the Swedish Rules for temperature rise, can be overloaded 20 to 25 % without in any way endangering the reliability. Conversely, with a given motor load, a transformer can be chosen for about 20 % less output, determined by the temperature figures just given. A reduction of the nominal transformer output by 20 % means a reduction in the no load losses of about 10 %, while at the same time the first cost is reduced. The danger in making such a reduction in the transformer output for country electrification will be seen to be very small. Cases in which transformers have been damaged as a result of long continued overloads are, in Asea's experience, very few, and in addition they have usually only been made possible by failure of the protecting devices to act. As motors reach their final temperature on load more quickly than transformers it will be seen that the former really act as a protection for the latter, since an overload will first be evidenced in the motor or motors. In order that the transformer output may be reduced without disadvantage it is necessary, however, to consider the load to which the motors connected to it will be subjected.

It is not clear without further investigation that the series of transformers at present in use with small no load losses are suitable, without any alteration, for overloading as stated above. It must be noted for instance that the voltage drop on maximum load must not be so great as to cause trouble in this respect. In Germany a reduction in the output of transformers used on farms has been attained by introducing special rules for agricultural transformers. The suitability of such special rules for agricultural machinery is considered below.

Having described the conditions which affect the economy of transformers for rural supply, and shown that the requirements cover great dependability and low no-load losses besides making desirable the introduction of special rules regarding temperature rise, we shall now give some particulars in a numerical form touching the two questions last referred to. For this reason investigations have been made which were limited to cover only the standard type of transformer which Asea has constructed for a considerable time, viz. the core transformer with cylindrical windings.

The question which first comes up for consideration is that of no load losses, the magnitude of which as stated above has a very considerable effect on the economy of such transformers. It may be wondered if the magnitude of the no load losses can be altered as desired, by altering the construction, between any limits whatever, and, in this connection, how the price in such cases is dependent on the different constructions.

Investigation of the various types in use shows that the no load losses can be considerably varied, although their magnitude is limited between an upper and a lower value. We shall now investigate these limits more closely, and will deal first with the question as to whether a transformer with a constant output can be constructed with no load losses of any magnitude. An increase in the losses has of course no practical interest unless the price of the transformer can be reduced at the same time. The no load losses, are, as is well known, constant x weight of iron x (induction)^2. As an increase in the weight of iron does not usually decrease the price, this weight must be reduced by increasing the induction in the core. By this means the number of necessary turns on the winding is lowered, and the copper used is decreased, so that a lower price results when the no-load losses are raised. It is easily seen that the price cannot be advantageously decreased in this way, if we remember that the no load current increases rapidly with increasing induction. *The no load current accordingly limits the upper value of the no load losses.* Transformers of the size here in question are usually designed with a no load current reaching 10 to 15 % depending on the output and voltage, and these values cannot usefully be exceeded.

The next question which arises is whether a transformer can be constructed with no load losses as small as may be desired. An appreciable lowering of the no load losses implies a lowering of the induction in the core. This

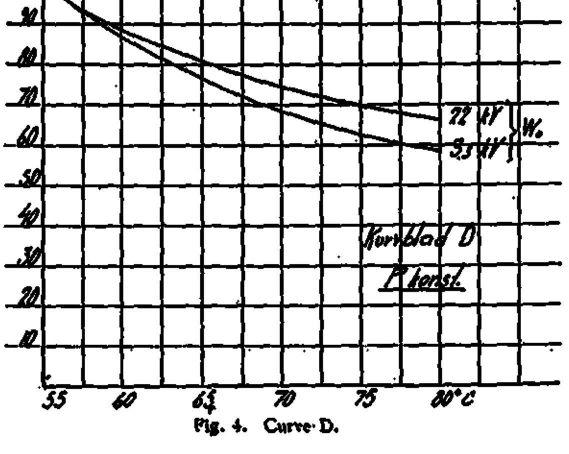


Fig. 4. Curve D.

means that a large number of turns must be arranged on the winding, which means an increased weight of copper. The price of the transformer is accordingly increased. At the same time the number of ampere-turns in the winding is increased and the short circuit voltage of the transformer largely depends on the magnitude of this figure, the short circuit voltage increasing with an increased number of ampere-turns. *The short circuit voltage determines the lower limit of the no load losses.* The limit for the short circuit voltage is, as previously stated, not exactly fixed; a value of 8 % at full load probably should not be materially exceeded, but is tolerable in view of the fact that these transformers are in general provided with tappings for ± 5 %, by the help of which the high short circuit voltage and voltage drop can be counteracted to a certain extent.

A large number of Asea transformer types have been investigated to find how the price, copper losses, and short circuit voltages alter with the variation of no load losses between the two limits found above, and the results are given in curve A fig. 1. Both price and no load losses are shown as a percentage of the value of the cheapest transformer, and the curves are drawn for voltages of 3.3 and 22 kV. It is seen that the no load losses can be brought down, by reducing the induction, to about 35 to 40 % of maximum value, depending on the working voltage, a reduction which is considerable, as the price is at the same time not raised by more than 30 to 45 %. With the power charges now ruling and with the load conditions which these transformers have to meet, this must in most cases be regarded as showing a considerable improvement in the economy of the transformers. It should be noted that the relations vary somewhat with different transformer sizes, and the curves given should be regarded as mean values obtained from investigations on sizes of 10 to 50 kVA.

Further, the particulars given in curve A are based on a temperature rise of 55°C in the windings corresponding to the permissible value in accordance with international standards. The corresponding temperature rise allowed by the Swedish Rules is 60°C, and by the German Rules 70°C, while the new German Rules covering special requirements for agricultural transformers in certain cases allow 80°C. An investigation of the extent to which these temperature requirements influence the price and no load loss of the transformer is of interest, and especially so regarding the question of the extent to which the lower limit, referred to above, for the losses is affected. The increased temperature rise allowed should obviously be utilized to reduce the price by saving material, which can be done in two different ways. The current density in the windings can be increased, or the cooling surface of the tank or the outer dimensions of the tank can be reduced, which brings down the price both for these details and the necessary quantity of oil. However, the dimensions of the tank are often limited by purely mechanical considerations, and when this is the case it will be seen that it is in general most suitable to use the first method, increasing the current density. It follows from this that less space is required for the windings, and this further affects the short circuit voltage of the transformer, this being increased. But in the foregoing it has been seen that the short circuit voltage determines the minimum value of the no load losses, and accordingly this limit should not be exceeded as a higher temperature rise is allowed. It follows from this that the induction in the core must be somewhat increased in order to reduce the short circuit voltage to the allowable value, and by this necessary increase in the induction the no load losses are increased with the temperature rise. In curve B (fig. 2) the same types have been used which furnished the material for curve A, but this time constant short circuit voltage has been maintained and the temperature varied. The curves obtained are of course still mean values; in this case however no tendency depending on the difference in the working voltage can be noticed so that only one curve holding for voltages from 3.3 to 22 kV is given.

In this connection it is of course most interesting to examine the dangerous effect of the temperature, and in this respect curve B gives less information, as in this both price and no load losses are variable. It is clear, however, that by a combination of curves A and B, curves can be obtained which are at any rate approximate, showing the variation of one of the magnitudes when the other is kept constant. These results are given in curves C and D (figs. 3 and 4). Curve C, shows the effect of the temperature allowed, on the price with constant no load losses. Raising the temperature limit from 55 to 70°C permits, as shown, a price reduction of from 8 to 10 % depending on the working voltage. Curve D shows the effect of the temperature rise allowed on the no load losses with a constant price. The reduction of these is very considerable, and in the belief that our customers receive better service with these low losses than with unnecessarily limited temperature rises, we recommend that such transformers should be designed with a temperature rise of

60°C in the oil and 70°C in the windings. As regards the correctness of these requirements we refer to the first part of this article.

In the German Rules which have been issued (see E.T.Z. 1922 No. 12), it has been reasoned that as normal power transformers can in their experience be worked with temperature rises up to 70°C without disadvantage, the corresponding limit for agricultural transformers can be placed higher. The standard allowed accordingly is a rise of 80°C in the windings. As agricultural transformers in the latest edition of the V.D.E. standards have been dealt with by the inclusion of certain special requirements, it is of interest here to review some of these more closely.

The output of such a transformer is given with two limits, e.g. 25/50 kVA. This means that in accordance with the Rules the normal output of the transformer is 25 kVA, but it can be overloaded 100 % to 50 kVA. The temperature rise allowed is then 70°C in the oil and 80°C in the windings, but the time of the actual overload is limited to 12 hours consecutive working and to 500 hours per year. Can these standards be justified? That the reliability of the transformer is risked by the higher temperature is shown by the particularly narrow margin one is obliged to have in respect to the actual load. It may further be pointed out that the losses in the transformers with maximum load consist almost exclusively of copper losses, so that we can calculate approximately that the temperature rise in the transformers with a load above the specified maximum load varies as the square of the load. Taking into account that these transformers are often in the hands of unskilled personnel who study neither the German Standardisation Rules nor the output plate of the transformer, it must be expected that there is considerable risk of overloading, and if this occurs the transformer will soon be damaged. Justification for these standards must further be sought in the reduction in price and losses which they make possible. With reference to curves C and D it may be noted that the gain obtained by changing from 70° to 80°C is only a few per cent. In our opinion, therefore, these Rules allow higher temperatures than are advisable.

It is further specified that the temperature limits of the Rules shall not be exceeded on a *continuous* overload of 60 %, counted from the lower power limit, thus in the above example 40 kVA. Under these circumstances it is difficult to understand the meaning of the lower limit (25 kVA). The Rules give the voltage drop as a reason. On this account the normal load thus has to be cut in two, but the transformer is nevertheless recommended for use up to double the capacity thus determined. A limit determined in this way, intended to be continuously exceeded by 60 %, appears rather artificial. In this connection it should be observed that the high capability of overload, 60 % and 100 % resp., has been made possible only by the introduction of this lower limit. The high overload capacity is namely always pointed out as a characteristic feature of these transformers. Nothing prevents further steps in the same direction. The nominal output of the above transformer may, for instance, be given as 20/50 kVA giving an overload capacity of 150 %.

It should also be noted that when giving the output in such a way the purchaser should satisfy himself as to the particular output on which the guarantees are based, as a misunderstanding on this point may make the figures appear more favourable than they actually are. Explanation of this is to be sought in the fact that when efficiency, short circuit voltage and voltage drop are guaranteed on full or half load, the full load is taken as being the lowest output limit. It is obvious that in this manner better data are obtained than if the corresponding guarantees were based on the upper limit, since the percentage values of short circuit voltage, voltage drop and copper losses increase proportionately with the load. As an example we may take a transformer 25/50 kVA, 10,000 volts, which in accordance with the German Standardisation Rules has the following guarantees:

Efficiency at full load	97.28 %
„ „ half „	97.32 %
Short circuit voltage	3.2 %
Ohmic voltage drop	1.9 %

In the above, however, "full load" is 25 kVA and "half load" 12.5 kVA. Basing the guarantees on the power output limit, the following far lower guarantee figures are obtained:

Efficiency at full load (50 kVA)	95.93 %
„ „ half „ (25 kVA)	97.28 %
Short circuit voltage at full load (50kVA)	6.4 %
Ohmic voltage drop at full load (50kVA)	3.8 %

We specially wish to draw attention to these methods of calculation, as from the corresponding experience we have had with our customers we have come to the conclusion that these German Rules are continually being misinterpreted as regards the particular points we have touched upon, and our own manufactures when directly compared with the guarantee figures given, accordingly appear to be inferior. The difference, it will be clear from the above, is only apparent.

Vesteras 1926, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

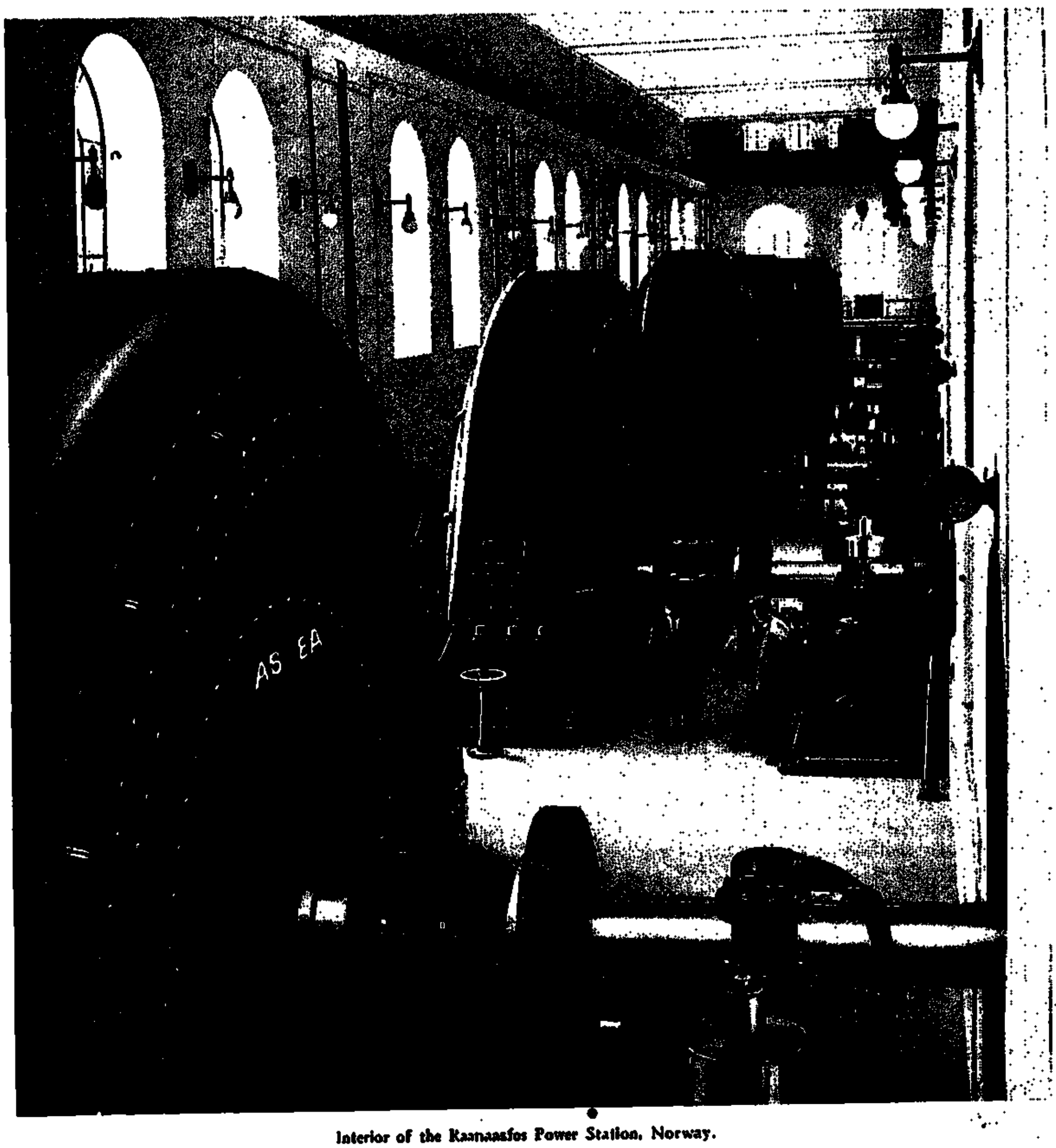
ALLMANNA SVENSKA
ELEKTRISKA A.B.
VESTERAS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

VOL. III
1926

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesteras, Sweden.

MARCH
No. 3



Interior of the Kaanaasfos Power Station, Norway.

GENERATORS FOR RAANAASFOS POWER STATION, NORWAY.

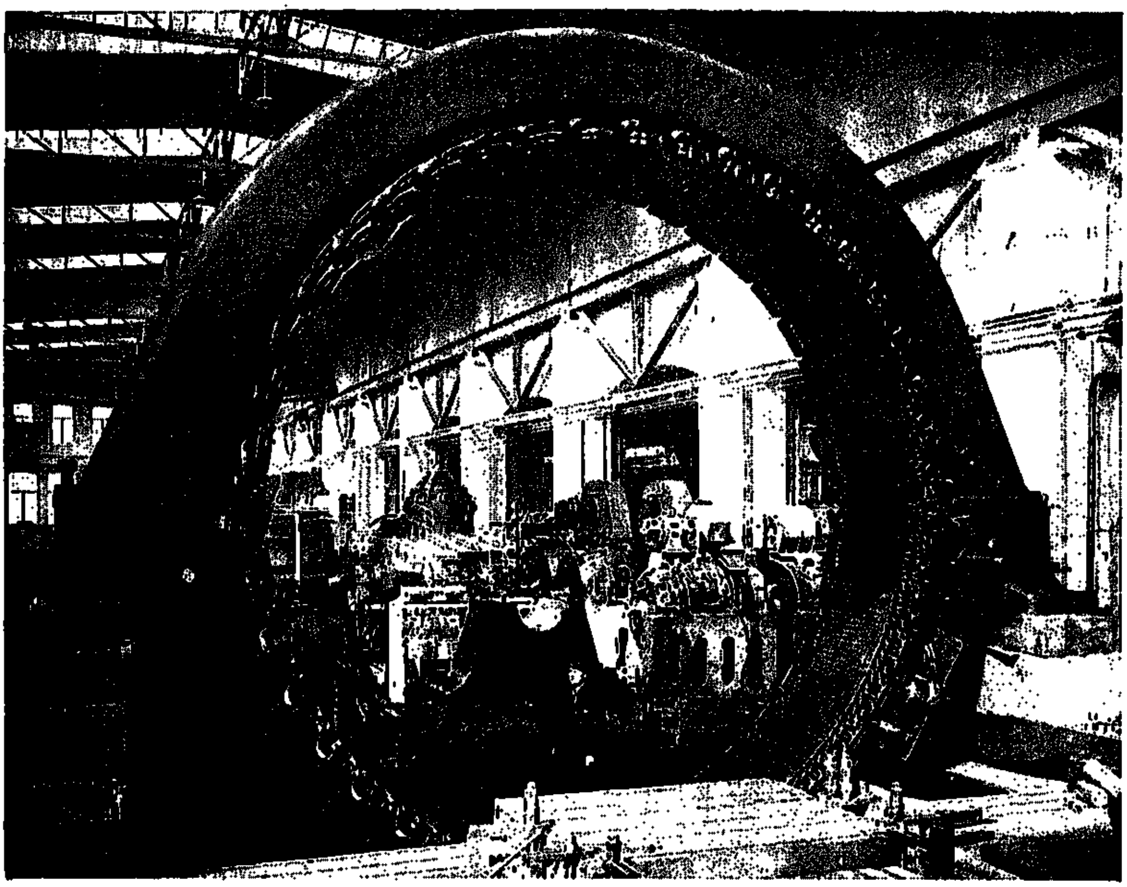


Fig. 1. Stator of one of the generators erected in the shops.

The Raanaasfos Power Station is situated on the Glommen near the point where the railway between Oslo and Kongsvinger crosses the river. The power station has been built and is owned by the Akershus County. Work was commenced in 1918 and the plant was originally designed to include six machines, although in the first instance only four were put in hand. These original machines were supplied by British and Swiss firms, and before they were completed it vas decided to proceed with the remaining two units. Asea was successful in obtaining the order in the spring of 1921 for the last two machines, in competition with practically all the large electrical companies in the world. The order included the two generators, together with the necessarry transformers and switchgear. The plant has now been running for some time, and some particulars regarding the generators can be given which will probably be of interest.

The two machines are for three-phase alternating current at 50 cycles, and designed for an output of 12,000 kVA, cos $\varphi = 0.7$, and 107 r.p.m. They are of ordinary horizontal type, totally enclosed and self-ventilated, as indicated in the figures. Asea has of course supplied many generators for larger output, but these particular machines are somewhat special on account of the low speed, which causes them to be among the largest which we have so far constructed.

In spite of the low normal running speed, the possible runaway speed is particularly high, and in the worst case can reach 205 r.p.m. For a machine of this nature a great number of constructional difficulties occurred which are not present in machines running at higher speeds and having smaller rotor diameters. In the first place the relatively low peripheral speed gives rise to considerable difficulty in obtaining adequate ventilation, and in the second place, owing to the high possible runaway speed, the rotor construction presents a problem which is hard to solve, since from the transport point of view it is necessary to divide the rotor along the diameter. In the present case

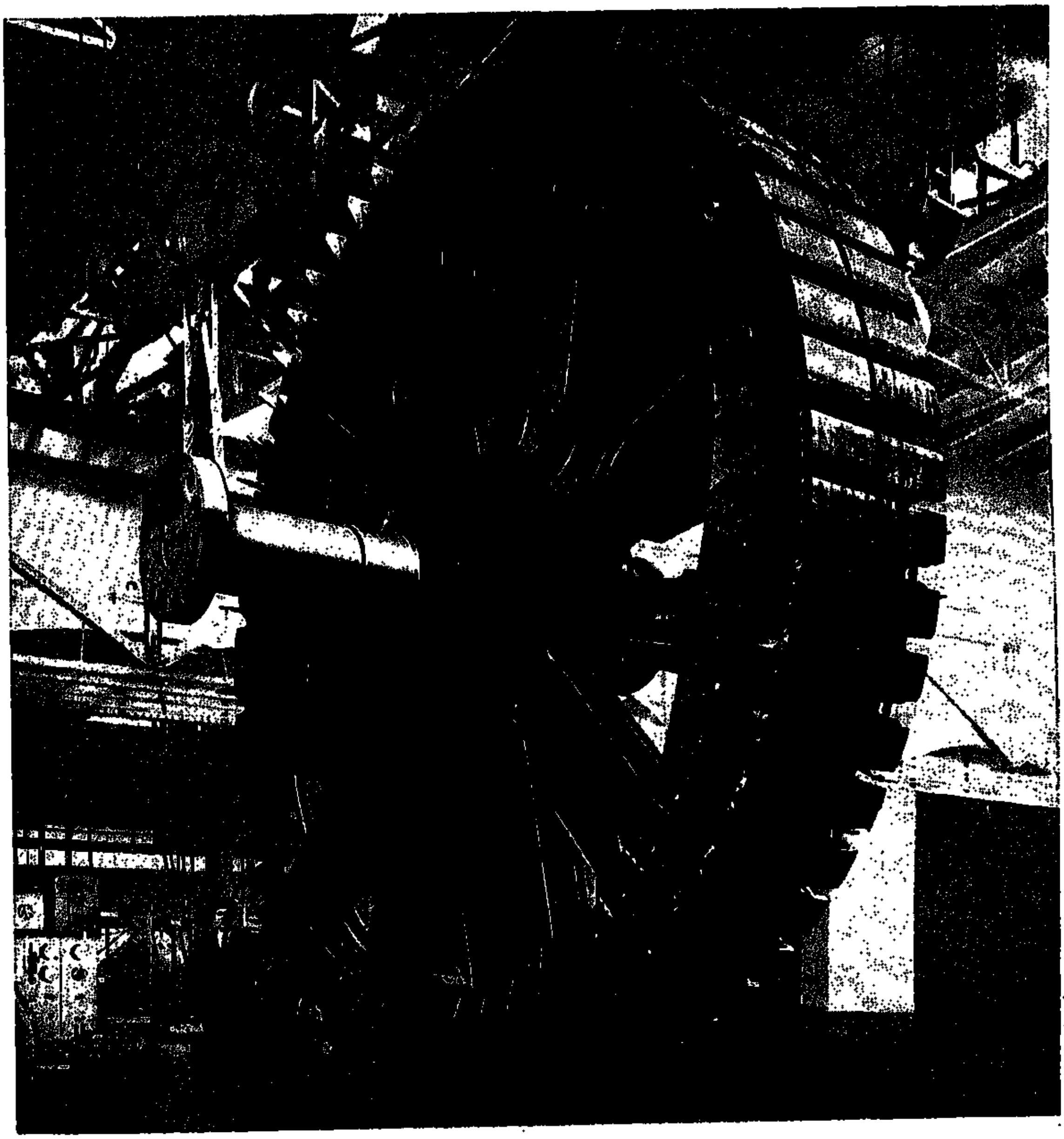


Fig. 2. Rotor of one of the generators.

the difficulties were considerably increased as the rotor was made from cast iron and not steel.

Construction from cast iron was made possible by the particularly high class material which is turned out by our foundries for exacting work, giving good ductility and high tensile strength.

The quality of the metal was controlled by taking a number of test specimens from the rings, these test pieces being removed from the points where bolt holes were bored. As each hole was bored careful investigation was made to ensure that the rings showed no porosity.

As the number of holes for bolts fixing the poles etc. was very high, a very good guarantee was obtained in this manner that the castings were not faulty in any way.

As will be gathered from the figures, the rotor is divided into four parts, into two along the diameter, and further on a plane at right angles to the shaft. In this way a wide ventilating duct is obtained in the middle of the rotor, which is necessary for cooling on account of the relatively great length of core plates and the difficult ventilation conditions due to the low speed. The semi-circular parts are held together by two large nickel steel caps which are shrunk on to carefully machined cylindrical seatings on the cast iron rings.

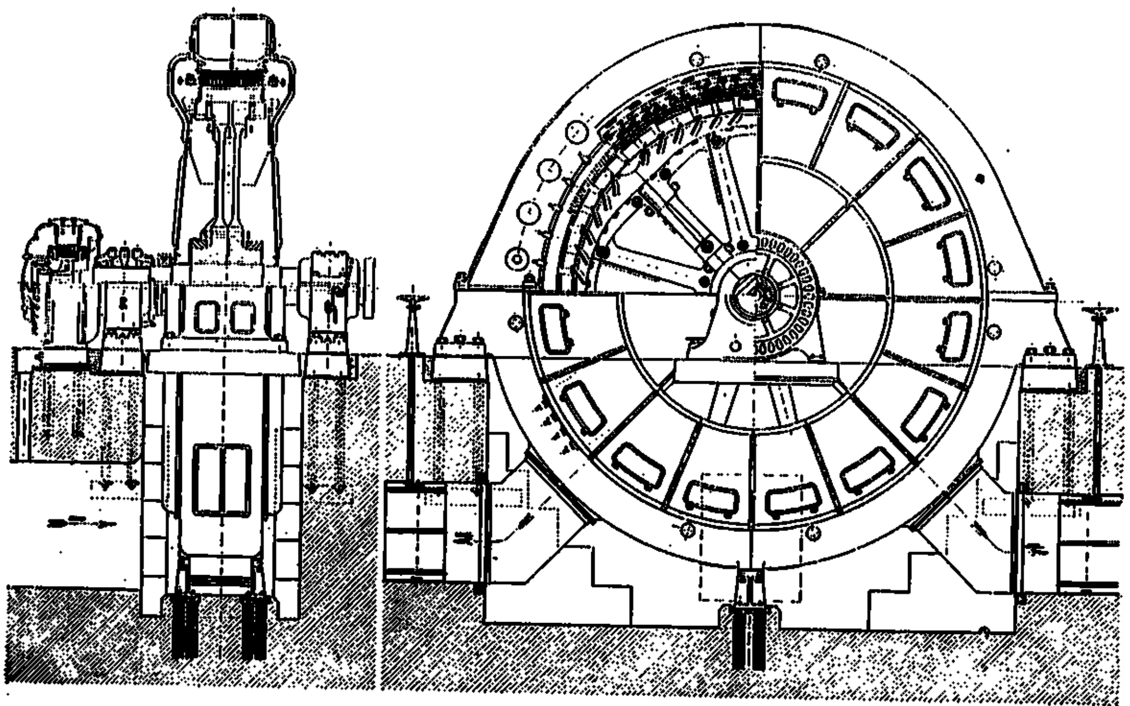


Fig. 3. 12,000 kVA three-phase generator for Raanaasfos Power Station, Norway.

These shrink caps thus hold together the two semicircular parts, and also keep the two vertical sections together; in the centre of the cap there are thus two divisions at right angles. In addition, the semicircular parts are held together by heavy bolts on the inner side of the ring. These bolts, however, are only subjected to a small part of the centrifugal stresses, as the resulting tensile stress in the ring falls practically at the foot of the surfaces retained by the cap. On account of the increased dimensions of the magnet wheel in the neighbourhood of the joints, there is an extra centrifugal force of approximately 260 tons at each of these points, and the dimensions of the arms must accordingly be increased to prevent the wheel being deformed from its true circular shape under the action of this additional force. If this were not done dangerous deformation stresses would arise. To enable the arms to deal with this force, it is not only necessary that they should be sufficiently strong, but also that the hub of the wheel should be sufficiently heavily designed; attention has been paid to this point, and the hub is also provided with heavy steel shrink rings. The poles, which are made from Siemens-Martin steel with laminated pole shoes, are held by screws to the magnet wheel. In order to prevent the possibility of the poles, under the action of centrifugal force, giving the cast iron wheel rings a deformation to a conical shape, both of the wheel sections are held together by strong bolts placed at the centre of the arms. It may be possible to give some idea of the difficulties when we state that the centrifugal force due to poles and rings reaches approximately 7,600 tons at 205 r.p.m. At this speed the peripheral velocity at the air gap is 66 m per second.

Fig. 4. One of the generators under erection in the power station.

For purposes of ventilation, in addition to the usual fan blades on the rotor rings, large fans are placed on the arms of the wheel. These fans ensure that the

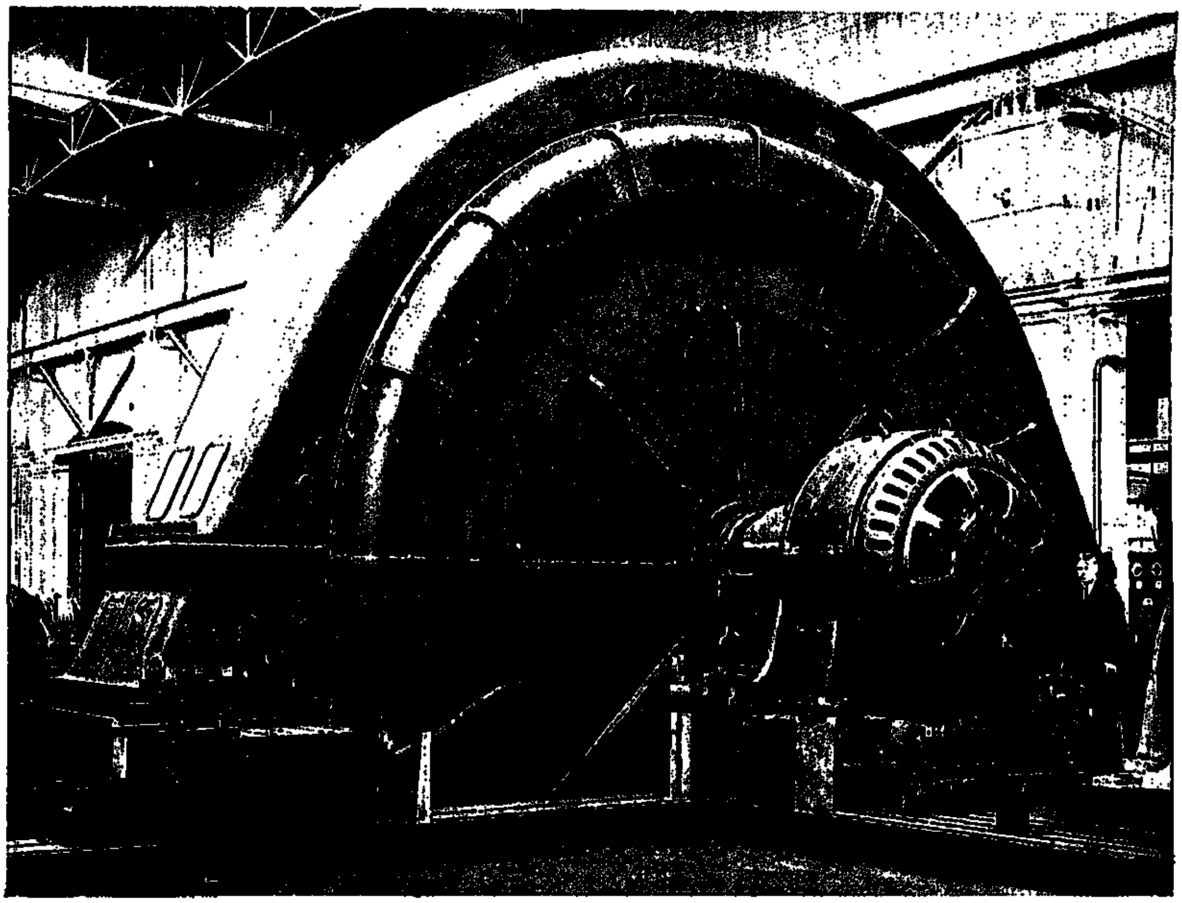


Fig. 5. Generator erected for test.

requisite quantity of air passes through the central air duct in the rotor. In addition they lessen the shocks on the smaller fans on the sides of the rotor, which would otherwise occur when the air moving radially encountered them.

The stator housing is, for reasons of transport, divided into four parts. Cast iron covers are fixed to the housing. The armature is built up of laminations which is fixed in the housing in the usual manner by wedges, and is held together by press flanges. The slots are of open type and provided with fibre wedges.

The armature winding is a two-plane coil winding with two slots per pole and phase. The number of conductors per slot is two. The insulation is in accordance with Asea's standard, and consists of U-shaped pieces of micanite round the separate conductors, and additional micanite interleaving strips. The insulation to iron consists of micanite sheet, which, in the usual way, is wound direct on the coil-sides. The insulation of the coil ends external to the slot consists of mica strip and heat resisting compound. The insulation is thus made from a material corresponding to the British Rules, Class B. In other respects the machines are not designed for a higher temperature rise than 50°. The field winding is wound from copper strip on edge in the usual way.

The bearings, which are designed for water cooling, have a diameter in the journal of 500 mm and are of our new standard design having a length of approximately 1.5 diameters.

All the standard tests were carried out, and among these the rotor was tested for overspeed and the machine short circuited when excited for 9,000 volts at no load. The insulation was tested with 22,000 volts for 15 seconds, and immediately thereafter with 15,000 volts for 5 minutes.

Other particulars can be gathered from the various illustrations given, which show the machines during different stages of construction and erection.

R. Liljeblad.

FORCED AIR COOLING FOR TRANSFORMER OIL.

With the general increase in the size of transformer units, the necessity has arisen for some form of forced cooling for the oil, and this condition is accentuated by the general desire to make better use of the active material in transformers, so as to obtain smaller dimensions and a lower price. Developments which have lately taken place in welding work have been responsible, in some respects, for a return to former methods, since tanks can now be constructed with sufficiently large cooling surface without the price becoming excessive, and this has given rise to a tendency to make use once more of self-cooled transformers. It must be admitted that this design embodies a large number of advantages, since the transformers are independent of all auxiliary machinery and can be left without attention, which in many cases means a considerable saving. For large stations where a staff is necessary for other reasons, this point of view cannot be maintained, and forced cooling is to be recommended on account of the very much lower capital cost.

Forced cooling can be arranged in several ways, of which the most simple and the one most generally in use is to provide the transformers with an internal water cooling coil made from some metal such as lead or copper which will resist the action of the water and any impurities dissolved therein.

A number of criticisms of this arrangement have been made, of which the most important is the danger of water leaking from the cooling system and entering the oil, in which case if the transformer is switched on a breakdown will immediately follow. This risk obliges manufacturers to take the greatest possible care in the production of the cooling coils, and at the present time any leakage due to faulty workmanship is a very unlikely occurrence. It has much more often happened, however, that the pipes have been burst due to freezing in cases where the transformer has been taken out of service during winter without emptying the cooling coils. Other disadvantages arise in cases where the available cooling water is not clean, and where it is accordingly possible for the cooling tubes to become silted up. Cleaning the tubes is always more or less difficult, depending on the nature of the impurities which have collected, but in most cases it means that the transformer must be switched off.

It has accordingly become the custom lately to arrange a cooling system separate from the

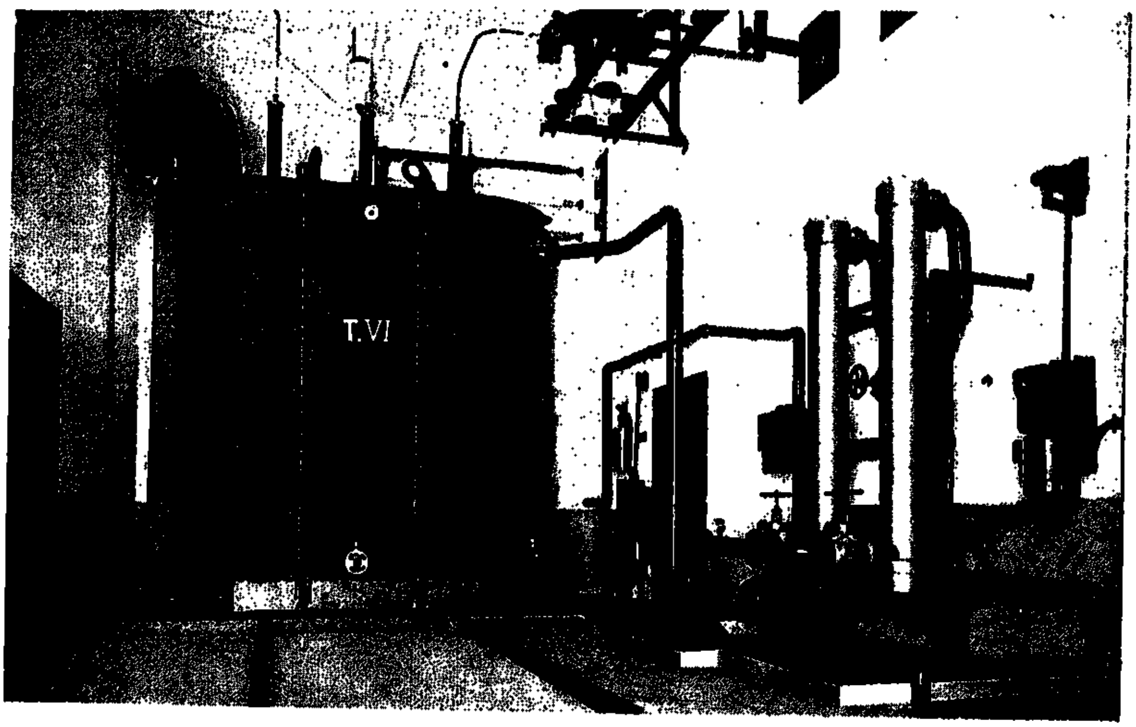


Fig. 1. 12,000 kVA transformer with Stal cooler.

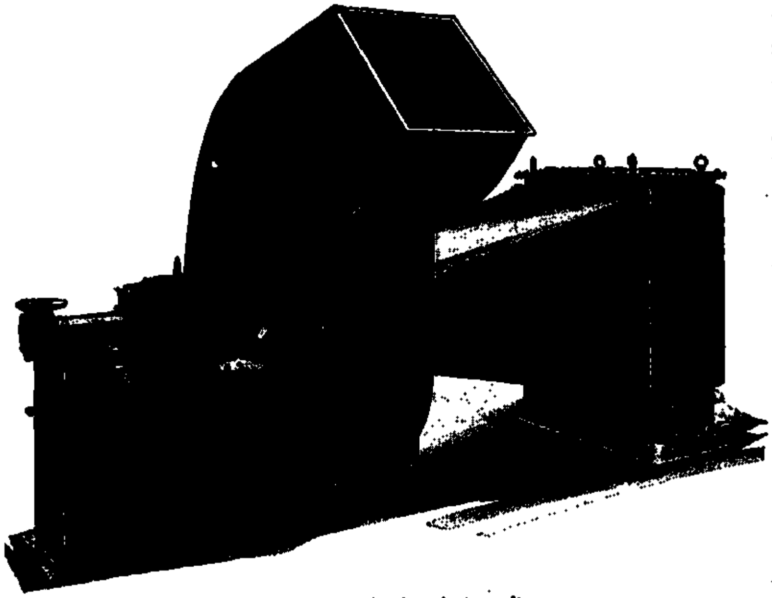


Fig. 2. Plant for forced air cooling.

transformer, consisting of a cooler through which the transformer oil is pumped, and in which it is cooled by means of water circulating in the cooler. Fig. 1 shows such an installation supplied by Asea, and furnished with a cooler manufactured by the Svenska Turbinfabriks Aktiebolaget Ljungstrom (STAL).

With such installations it is possible to design the cooler so that the oil is at a higher pressure than the water, and the risk of a leak in the system permitting water to enter the oil tubes is thereby eliminated. This is undoubtedly a great advantage, but it will be noted that the other disadvantages remain and there is still risk of freezing and silting up.

A fairly obvious manner of avoiding the disadvantages attending the use of water as a cooling medium is to employ compressed air as an alternative, and it is rather surprising that this has not been attempted earlier. This method appears to have been taken up first of all by Asea, and a little later by a German firm quite independently, and it follows that Asea is the real pioneer in this direction, having obtained orders for the first 10 installations by March 1923, delivery being effected during April 1924. These first examples of air coolers were used on the locomotives of type Od on the Riksgrans Railway, Sweden, and dissipate 30 kW with a temperature rise in the oil of 40° C. above the temperature of the incoming cooling air. The same cooling system is being used for the 50 locomotives of type D now being supplied for the Stockholm—Gothenburg Railway, and as regards these coolers we can refer to an earlier article in Asea-Journal (Oct.1925). We are now able to show some illustrations of the first stationary plant which has lately been supplied to the Royal Waterfalls Board for the step-down transformer station at Moholm, Sweden. Fig. 2 is a side view of a unit, showing the cooler itself placed on the right and connected to the fan by a conical shaped air duct; the cooler is placed in the fan intake. On the extreme left the oil pump will be seen, fan and pump being driven by a common motor. The unit is designed for installation out of doors without protection, and for this reason the motor is totally enclosed, all other apparatus belonging to it being carried in the pedestal supporting the motor, the access door being visible in the photograph. The air outlet is directed upwards so that the draught will not cause any inconvenience, and in the opening is a simple signalling device which actuates an alarm if the fan should stop running. Fig. 3 shows the cooler from the intake side, and the design on the cooler will be quite clear from the photograph, any further description being superfluous.

This cooler dissipates 157 kW with a temperature rise in the oil of about 35° C and with a circulation of 18,500 kgs of oil per hour and 14 m³ of cooling air per second. Under these conditions the pump and fan require 16 h.p. or 7.5 % of the losses carried off. The velocity of the air at the intake remains at

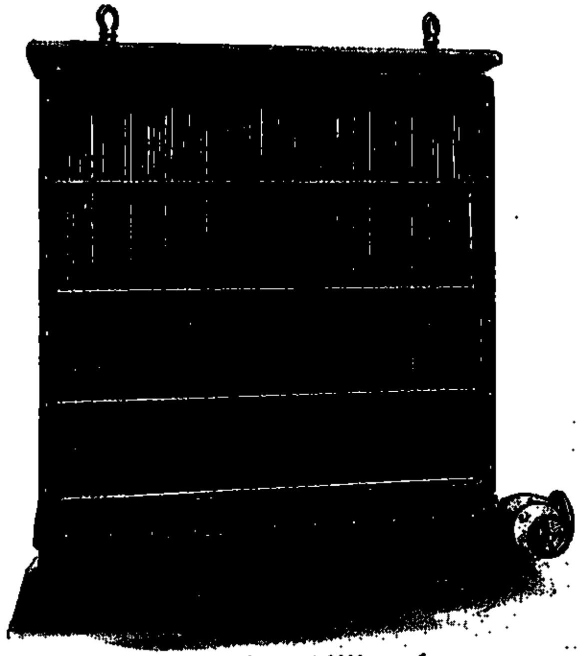


Fig. 3. Oil cooler for 7,000 kVA transformer.

about 10 m per second, and does not give rise to any troublesome draught.

The great advantage of the system as stated above is that water need not be used. In districts where clean and suitable cooling water is not available, it may be expected that the system will quickly be used to a very great extent.

As regards the cost of the installation, the purchase price is somewhat higher than for a unit employing circulating water, but the erection costs are considerably lower as it is not necessary to run piping for the water, which is often an expensive matter, depending on local conditions. As regards running costs for the new system compared with the old, it may be pointed out that there may be a very big advantage where water cannot be obtained free.

These coolers are built by Asea for a maximum cooling effect of 250 kW with a 40° C temperature rise. For larger installations two units are recommended, each one dimensioned for half the power. As the drop in temperature between windings and oil falls off as the square of the load, the oil temperature on low outputs can be permitted to be higher than at full load, and on this account it is usually only necessary to use one unit up to about $^3/_4$ full load without the temperature rise of the windings exceeding the normal amount. The arrangement also permits of a considerable reserve, since the load can be kept up to 75 % of the maximum during the time when one of the units requires overhauling.

When two coolers are purchased there are also greater possibilities for making use to the fullest extent of a possible lower surrounding air temperature than may have been allowed for. The coolers are naturally dimensioned to provide the required amount of cooling by the standardisation rules adopted, and which all permit a cooling air temperature of 35° C or higher. With lower temperatures of the cooling air it is accordingly possible to reduce the capacity of the cooler without running the risk of exceeding the allowable temperatures, and a calculation shows that in general one of the two coolers is sufficient to carry off the total losses when the temperature of the cooling air goes down to 0° C or below. Working can thus be arranged so that during winter, and also during periods of decreased load, one cooler only is in service, while the second cooler is put into commission during periods of full load and in the summer.

These coolers are of course suitable for purposes other than have been described here, namely for cooling any liquid which does not have any chemical action upon iron.

E. Stenkvist.

AUTOMATIC REGULATING EQUIPMENT FOR THE RANDERS—AARHUS TRANSMISSION SCHEME, DENMARK.

For some considerable time Asea has made a speciality of transformers with adjustable ratio in connection with winding couplers, which make it possible to vary the voltage supplied by the transformer without interrupting the load. The principle of these winding couplers is now so well known that it is not necessary to enter into any description here. Lately such adjustable transformers have been largely used in connection with voltage regulation, and for connecting two different power networks; for these purposes the operation has in several cases been arranged so as to be entirely automatic. An interesting example of what can be done in this connection is furnished by the equipment which was recently delivered through the firm of consulting engineers, Eriksen & Sardemann, to the Aarhus Electricity Works for connecting two power supply schemes in Denmark.

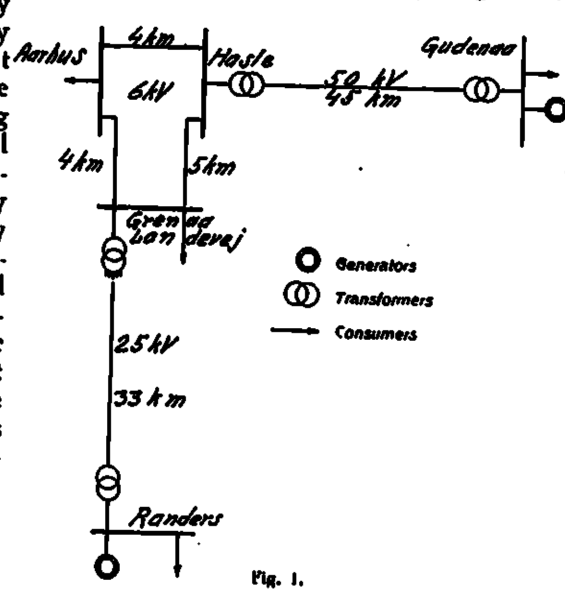


Fig. 1.

From the hydro-electric station at Gudenaaen (see the diagram, fig. 1), which lies at a distance of about 50 km, a 50 kV transmission line is run in to a transformer station in the neighbourhood of Aarhus, where the pressure is transformed down to 6 kV, after which the power is carried on into Aarhus and also to a further transformer station in the neighbourhood of Aarhus, from which energy is supplied to the sur-

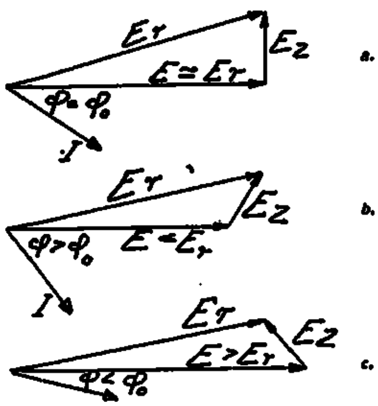


Fig. 2.

rounding agricultural districts. The last named transformer station, besides being connected with Aarhus direct, is also coupled up to Randers power station by a 25 kV transmission line 33 km in length, which is connected to the 6 kV network through an adjustable 1,500 kVA transformer which will be described here.

It was desired to make the regulation of this transformer fully automatic, so that when the two supply sources were operating in parallel they would work with approximately the same power factor,[1] and also naturally at the same time it was desired that the variations in pressure should be as small as possible when one or other of the supplies was disconnected.

Strictly speaking regulation should be carried out on different principles with the stations working individually or in parallel, but since, with the exception of pressure, there is hardly anything but the direction of power to use for the regulation, and this direction can vary on either system of running, a scheme of regulation had to be sought which would operate in a satisfactory manner, both for individual and parallel working. On the other hand, there is no difficulty in regulating on different principles when the power is flowing in different directions.

The problem was settled in such a way that with the power flowing in the direction of Randers the regulator keeps the pressure constant on the Randers 10 kV busbars, while when the power is in the opposite direction the pressure is kept constant on the 6 kV busbars at the transformer station with a power factor adjustable within certain limits, but increasing or falling with the load if the power factor is higher or lower respectively than that for which the regulator is adjusted. The regulation with power flowing in the direction of Randers is obtained by means of a contact relay which is excited by the pressure at the transformer station reduced by the voltage drop in the transmission line. This voltage drop is obtained by making use of an artificial line corresponding to the actual transmission line, and which is traversed by the secondary current of a current transformer. Thus the contact relay under all conditions is acted upon by the voltage at the Randers station and accordingly keeps this voltage constant.

The manner in which the regulation acts when the Randers station is disconnected will be clear without further explanation. If, on the other hand, the Randers station is connected but is only supplying part of the necessary power, so that power is still transmitted from the transformer station to Randers, the conditions are somewhat more complicated. Since the transformer regulator is in equilibrium only at a certain voltage in Randers, it is not possible to adjust the voltage at Randers by means of the generator fields. For example, a reduction in the field strength on the generators at Randers certainly has a tendency to reduce the voltage there, but this tendency is immediately counteracted by the regulator at the transformer station which raises the voltage on the 25 kV side to an extent which restores the pressure at Randers to its original value. This naturally results in an increased pressure on the 25 kV side at the transformer station, *i.e.* a greater voltage drop in the line, which with constant kW power means that more wattless energy is transmitted from the transformer station to Randers. The reduction of the magnetisation at Randers has accordingly not affected the voltage at Randers, but increased the amount of wattless power carried by the transmission line.

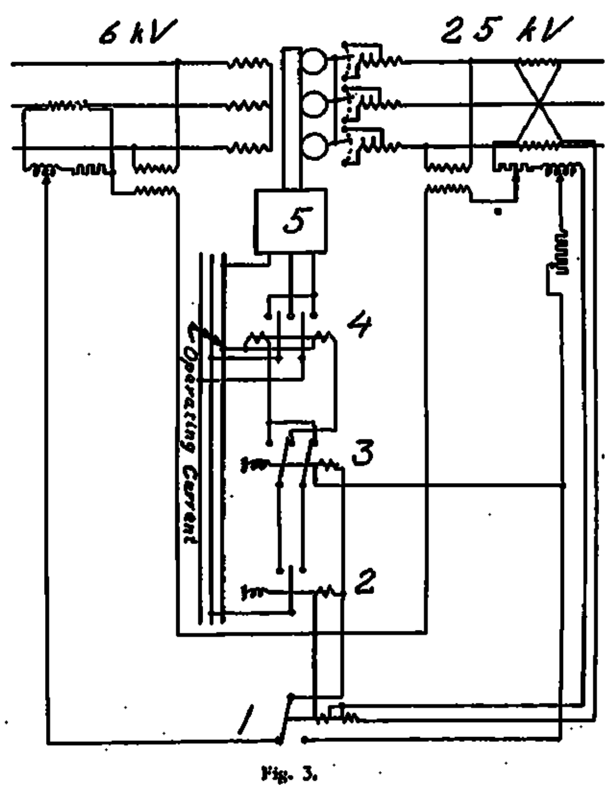


Fig. 3.

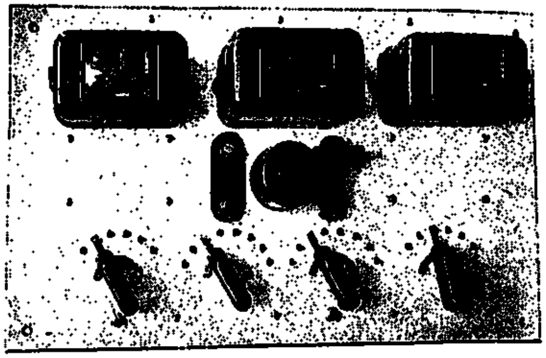


Fig. 4. Operating panel.

In this way the reactive power which the Randers generators have to supply is reduced in a corresponding degree, which means that these machines can work with the same voltage as before in spite of the decreased magnetisation. The result of this regulation is accordingly that when the Randers station is disconnected one is able to effect regulation with a constant voltage at Randers, independently of the magnitude and power factor of the load. With parallel working it is similarly possible to regulate at constant voltage, while the power factor is adjusted by hand through the generator magnetisation at Randers.

Regulation of power factor can, of course, also be carried out automatically if a suitably arranged static regulator is installed at Randers. By over or under compounding the regulator at Aarhus it is possible in this way to adjust the regulation as desired within wide limits.

The regulation when the direction of the power is away from Randers is effected by exciting the contact relay with a voltage E on the 6 kV side and a voltage drop E_z in an impedance exited from a current transformer. This is so designed that the voltage drop with the desired power factor is at right angles to the voltage E, when the resultant voltage E_r (see fig. 2 a) is, practically speaking, independent of E_z which is proportional to the load. If, however, the power factor is lower than the fixed value, the vector then lies as shown in fig. 2 b and the voltage E must fall with the load in order that E_r may be constant. If the power factor is better the conditions are exactly the opposite, as shown in fig. 2 c.

With parallel operation the effect of this regulation depends not only on the power factor of the load, but also upon the adjustment and action of the automatic regulators in the Gudenaaen station and upon how the reactive power is divided between the two stations. By adjusting the regulator for a suitable no-load voltage and a suitable value of the power factor, it is, however, possible to obtain a very satisfactory result. It is easily seen that the regulator tends to divide the reactive power evenly between the two stations. If, for example, Randers supplies more reactive power than that which corresponds to the adjusted value, the regulator reduces the voltage on the 6 kV busbars in the transformer station. Since the voltage at the Gudenaaen station is maintained approximately constant by automatic regulators, this means an increased voltage drop from the Gudenaaen station to the transformer station which can only be obtained by the Gudenaaen station taking over more of the reactive power. If the voltages in the two generating stations are kept constant, it follows that the station which is subjected to the least active load takes over a larger proportion of the reactive load. Actually the regulation at the Gudenaaen station is carried out in such a way that the voltage there rises somewhat on increased load. In this way the tendency referred to above is counteracted to some extent, and the reactive power is not thrown to such a degree on to the least loaded station, and accordingly it is possible to obtain a good division of the reactive power.

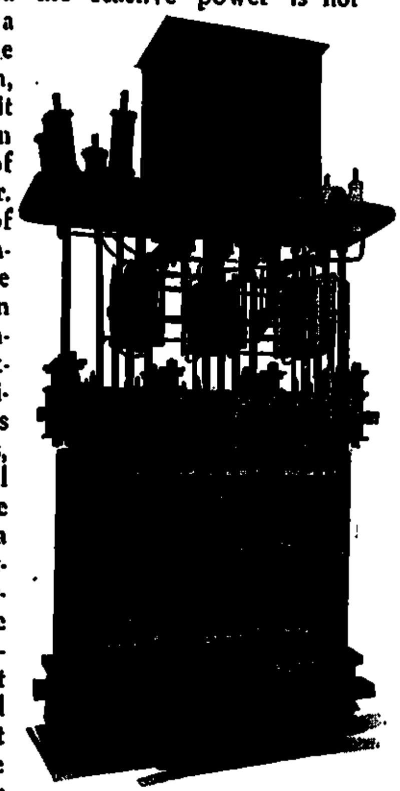


Fig. 5. Transformer type TO 57, 1,500 kVA, 24,000—30,000/6,000 volts. High tension side.

The principle of the scheme of connections for the equipment is shown in fig. 3. The contact relay 2 is excited, when the direction of power is towards Randers, from a potential transformer on the 25 kV side, and a variable compensating impedance corresponding to the line. The compensator could most easily be supplied from the current transformer in one phase, but in order to obtain correct phase relation the potential transformer should then be connected between the corresponding phase and the neutral. Since for practical reasons this cannot very well be done, the potential transformer is connected between two phases, and the compen-

sator supplied from two cross connected current transformers placed in the phases to which the pressure transformer is connected.

When power is being supplied from Randers the contact relay is fed from a potential transformer on the 6 kV side in conjunction with a compensator which can similarly be adjusted. Here the current transformer which supplies the compensator is placed in that phase in which the current with $\cos\varphi = 1$ leads the voltage of the pressure transformer by 90°. If the compensator were provided with purely non-inductive resistance, the compensator voltage with $\cos\varphi = 1$ leads the main voltage by 90°. A non-inductive compensator thus corresponds to a system working with $\cos\varphi = 1$. If the compensator is made more or less inductive, this results in the voltage drop in it being further displaced by a certain angle forwards, which means that the current must have a certain inductive phase displacement in order that the two voltages shall be at right angles to one another. By adjusting the reactance of the compensator it is accordingly possible to arrange it for any desired value of power factor. The resistance is fixed so that the adjustment is not too complicated.

The value of the voltage at no load for which it is desired that the regulator shall operate is set for the 6 kV side by an adjustable screw on the contact voltmeter. After this adjustment has been made the voltage on the 25 kV side is set by means of an adjustable resistance. Changeover from the 25 kV side to the 6 kV side is made with a double contact power directional relay.

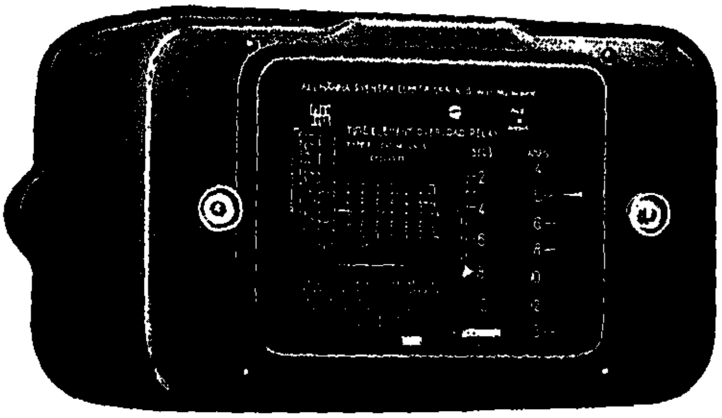
The contact voltmeter, through a change-over relay 3 operated by the power directional relay, feeds an operating relay 4 which closes the circuit of the operating motor 5 in such a manner that two phases are connected in different order, depending on whether the voltage is too high or too low, thus giving the motor a different direction of rotation. The change-over relay is necessary because the regulator, for a given voltage alteration, must be driven in different directions according to whether the contact relay is worked from the 6 kV or the 25 kV side. The winding coupler is placed on the 25 kV side, so that an increase of the pressure on this side means an increase in the number of turns in the winding, while on the other hand an increase in the pressure on the 6 kV side means a decrease in the number of winding turns. For this reason the connections between the contact relay and the operating relay of the change-over relay are changed over at the same time that the power directional relay operates.

Fig. 4 shows the operating board. In addition to the apparatus referred to, this is provided with a two-pole push button for non-automatic electric operation, and two plug contacts for changeover from automatic to non-automatic regulation.

In this case the winding coupler is included with the transformer for which the primary voltage is 6 kV, and the secondary voltage 24—30 kV adjustable in eight steps (nine positions) of 750 volts each. Fig. 5 shows the high tension side of this transformer. The contacts are arranged on two bakelite slabs per phase placed above the upper yoke. All sparks on breaking are taken up by a strongly constructed change over switch, which, together with the coupling resistance, is placed in an oil tank above the transformer. No oil circulation takes place between this tank and the transformer. Thus in the event of the oil being carbonised, due to sparks on reconnection no damage can be done to the transformer.

The whole of the equipment, including relays and apparatus, was manufactured and delivered by Asea.

A. Bauer. I. Herlitz.



TIME LIMIT OVERLOAD RELAY TYPE RI

SOME ADVANTAGES.

1. The initial cost is low.
2. There are no delicate parts or cords, and the relay is of sound engineering construction throughout.
3. The power consumption amounts to 8 volt amps. only, and is practically independent of the current setting.
4. The induction disc commences to rotate on very light load and indicates at a glance that the relay is in working order.
5. "Floating" is impossible. The device operating the contacts does not begin to move until the current has reached the value corresponding to the scale setting.
6. The relay is self-resetting. If an overload ceases before tripping has occurred, the relay resets itself immediately the current has dropped to 85 % of the current setting. Tripping due to successive intermittent overloads is thus avoided.
7. Settings for tripping current and tripping time are independent, and are adjustable within a wide range. They can be varied with the plant on load without the risk even of opening the current transformer secondary circuit.
8. The time curve has a very gradual bend, and the definite time which is reached with a current of about 5 times the ampere setting is long enough to permit safe selective tripping of a large number of oil switches, even with the heaviest overload. The shape of the time curve remains unchanged at all current settings.
9. If required the relay can be set for instantaneous trip with overloads of 4, 6 or 8 times the setting on the amp. scale. This feature is separate and distinct from the time setting.
10. The relay is short circuit proof, and the coil can withstand a momentary overload of 500 amps. on the 5 amp. tapping.
11. The contacts have a quick and definite action and can be used either for closing or opening circuit by reversing the bracket carrying the fixed contact.
12. The relay can be easily supplied with an indicating device to show which relay in a group has operated.

ASEA

VESTERAS — SWEDEN

Vesteras 1926, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

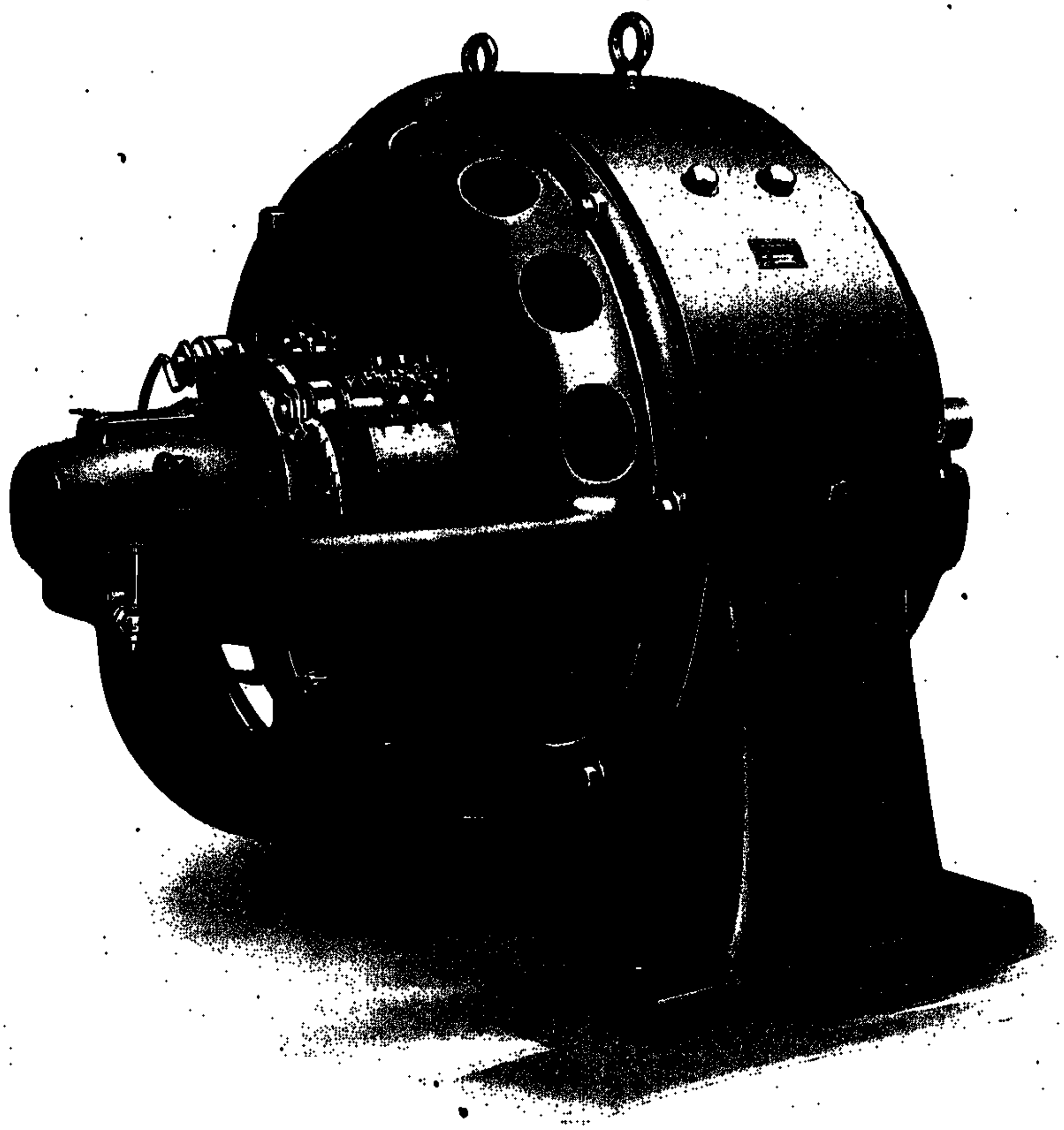
ALLMANNA SVENSKA ELEKTRISKA A.B.
VESTERAS — SWEDEN

SWEDISH GENERAL ELECTRIC LTD
5. CHANCERY LANE—LONDON

VOL. III
1926

All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesteras, Sweden.
Permission is given to reprint articles or extracts from this journal, on condition that the name — Asea-Journal — is clearly stated.

APRIL
No. 4



DC motor type K, 150 h.p.

AUTOMATIC PUMPING EQUIPMENTS.

The art of lifting and transporting water is as old as civilisation itself. The development of modern knowledge by which use has been made of pumps and pipes, has for the first time provided a real solution of the problem. The availability of water is one of the greatest necessities for civilisation and industry, and the supply of water is one of the services which modern knowledge of hydraulics has made possible. The great importance of cheap water can be appreciated from the consumption which is recorded for different centres of population. Thus small villages make use of from 12 to 36 galls. per 24 hours per head of population, while larger towns in Europe use from 25 to 75 galls., and a number of American towns from 50 to 100 galls. Pumps also play an important part in most industrial activities. In the chemical industry, such as cellulose and paper manufacture, and also in textile mills and in the provision industry, pumps are not only used for the transport of water, but also for moving finished and unfinished materials. In the textile industry for example, about 100 galls. of water are employed for each lb. of wool which is dealt with. Every steam engine provided with a condenser uses from 65 to 85 galls per h.p. hour.

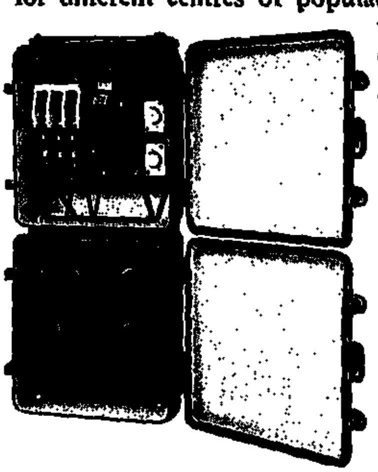


Fig. 1. Ironclad starting apparatus for direct starting of three-phase motor with self-contained starting winding. 30 h.p., 380 volts, 50 cycles. Protective relays as per diagram, fig. 12.

I. *General Technical Considerations.*

The power which the driving motor of a pump has to develop depends on the height to which the liquid is to be lifted, upon the quantity of liquid, and lastly on the loss of head in the piping. The size of the driving motor is determined from this power. As sources of power, steam, gas and electricity, come into the question. The last is at present the most used on account of many striking advantages, among which may be mentioned cheapness, simplicity in operation, easy installation and small space requirements.

A further advantage is that the drive can be made automatic in a perfectly easy manner, and various questions depending on this are treated below.

The construction of the pump and the arrangement of the piping system only affects the automatic arrangements in that a somewhat different electrical equipment may have to be used. Thus the starter which is used depends upon the choice of the type of pump, *i.e.* whether reciprocating, centrifugal etc. Automatic starting of large reciprocating pumps is particularly difficult, and these should not, if possible, be started under load, but with a special valve in the delivery pipe open. Only the smallest reciprocating pumps should be started directly against pressure, in order that too great a load may not be thrown upon the electric supply. For automatic starting, a starting torque of at least double the normal is required, and this can be still greater if large flywheel masses or long delivery pipes containing a great weight of water which must be set in motion are in question. Centrifugal pumps are easier to start, this depending on the character of their load torque, which increases approximately as the square of the speed. During actual starting, a centrifugal pump takes from 30 to 40 % of full load torque, and only requires full turning moment at full speed. Most pumping stations which are automatically operated are equipped with centrifugal pumps.

Lastly, the protective apparatus which is used excercises considerable influence upon the automatic drive. We must here take account of faults which may arise in the pumps and delivery pipes, against which it is desirable to guard. Some of these faults are given in the following paragraph.

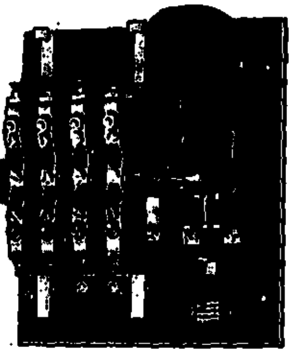


Fig. 2. Automatic changeover switch with thermal time lag, type AKV 4/60. Arcing shields removed.

The suction pipe of the pump is provided with a foot valve, so that it is always kept filled with water, while the pressure pipe or delivery pipe is furnished with a delivery valve. A centrifugal pump can only draw water when the suction pipe is filled with water, since of itself only an inconsiderable vacuum is obtained when it runs in air. If air enters the pump, considerable heating may take place, so that protection against starting or

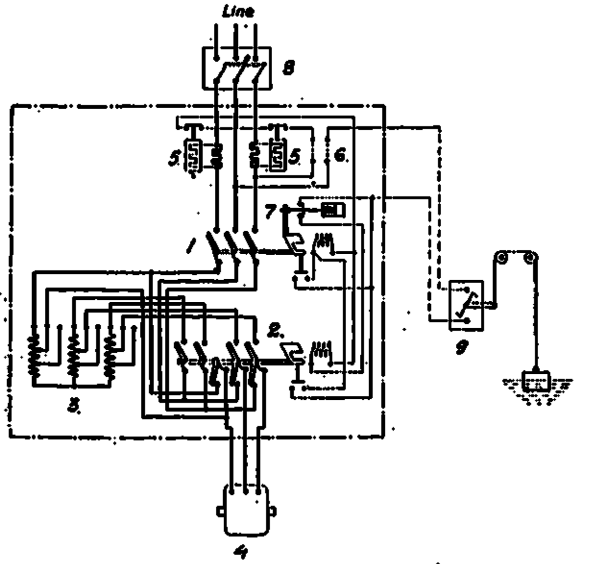


Fig. 3. Automatic autostarter.

1. Primary contactor.
2. Changeover contactor.
3. Autotransformer.
4. Motor.
5. Overload relay.
6. Fuses for operating circuit.
7. Time limit relay with air damping.
8. Disconnecting switch.
9. Float switch.

running under such conditions must be provided for. If the delivery valve for any reason (e. g. low speed) does not open, or if there is a stoppage in the delivering pipe, the pump will not operate properly. This also introduces the danger of overheating. The bearings of the pump may run hot, if, for example, the cooling of the thrust bearing fails, in which case there is a danger of the bearing seizing up, and on this account a signalling device should be provided. Lastly, foreign material may enter the pump, so that it cannot rotate and is brought suddenly to a stop. Freezing is a condition which can also interfere with the proper running.

Fig. 4. Hysteresis starter (cover removed).

II. *Considerations regarding Choice of Electrical Equipment.*

It is impossible to give a general rule as to the manner in which an automatic pumping station should be equipped. We shall, however, give a few important points which must be considered in the supply of plant for automatic drive. For pumping installations all voltages and systems of distribution can be used. Pumping plant is often a relatively small unit which is located at a considerable distance from the point at which the water is required, and the most suitable electrical requirements cannot always be obtained.

With continuous current the voltage is determined at the outset. When using alternating current, however, we often have a free choice, since the voltage can easily be transformed up or down. For the motors a low voltage such as 220 or 380 is most common, and is also most suitable. High tension motors are in general not to be recommended, since their windings, on account of the frequent starting and stopping, can be easily damaged by excess pressures, and must on this account be protected by charging resistances. With automatic drive this consideration considerably increases the cost of the apparatus.

The choice of the most suitable type of alternating current motor is an important question. We have the standard squirrel cage motor, the three-phase motor with selfcontained starting winding, and the standard slipring motor to choose from. In certain particular cases three-phase commutator motors or single-phase motors merit consideration. The commutator motor is used in cases where the regulation of the speed of the pump in relation to the necessary quantity of water is required. The single-phase motor may be necessary on single-phase supplies or lighting supplies, but in general should only be considered for exceedingly small outputs. These two last classes of machine, however, are really exceptions. The other types are of incomparably greater importance.

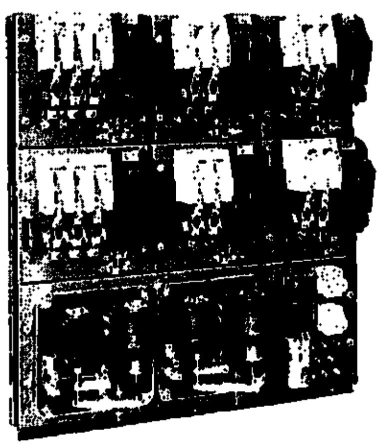


Fig. 5. Contactor panel for AC motor. 22 h.p., 380 volts, 50 cycles. Starting in accordance with fig. 8.

The slipring motor has high starting torque, and by the use of a suitable starter can be made to run up to speed exceedingly smoothly. The slipring arrangement must, however, be solidly constructed and designed so that the brushes can be left continually in service. It is of course possible to provide an automatic brush lifting arrangement, but this naturally is a complication.

The standard squirrel cage motor possesses considerable advantages, due to simple construction and cheapness. It has, however, a poor starting torque, and the starting current is high in comparison with the normal current taken during running. A considerable improvement in this respect is provided by the three-phase squirrel

Fig. 6. a) Starting current for motor type MK 21, 380 volts, 50 cycles, 22 h.p. Starting with torque increasing directly with the speed. Load current = 19.5 amps effective. Starting with two secondary contactors. b) Torque curve.

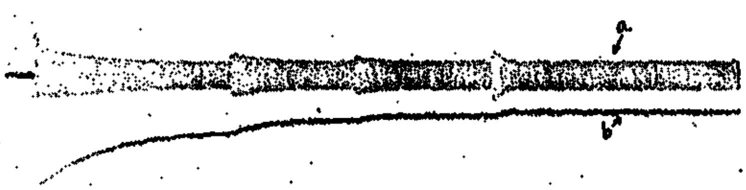


Fig. 7. Curve as in fig. 6, but with three secondary contactors.

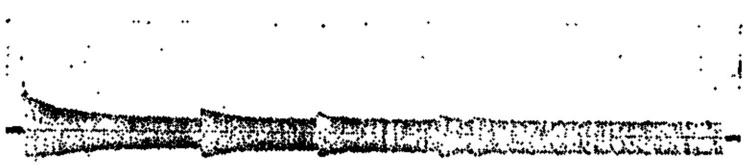


Fig. 8. Starting current for motor type MK 21, 380 volts, 50 cycles, 22 h.p. Starting with torque increasing directly with the speed. Normal current = 19.5 amps effective. Starting with four secondary contactors.

cage motor with high starting torque, and this just fills up a gap in pumping equipments between 5 and 30 h.p.

In choosing suitable electrical equipment the character of the supply, *i.e.* the voltage drop which occurs in the line when a relatively large and sudden load is thrown on to it, must be considered. If flickering cannot be allowed on the lamps which are connected to the supply when the motor starts, then it is desirable to select a motor which starts up smoothly, but in other cases naturally it is most advantageous to take the simplest possible equipment.

As a last important factor the operating gear may be referred to. The distance between the pumps and the reservoir from the place from which the automatic starting and stopping is to be conducted, exercises an influence on the whole plant. In the same degree also the layout of the line must be considered, whether this passes the pump house only, or both the pump house, operating place etc.

The above points have been mentioned in order to show that there is no universal solution to the problem of arranging a satisfactory automatic gear, but the question must be gone into in each and every case, giving attention to the local conditions and economical considerations. In the following the different elements will be briefly referred to, which in general go to the making up of an automatic pump equipment. These can be subdivided as follows:

1) The automatic starter and primary switch.

2) The operating and supervisory control apparatus.

3) The protective apparatus and arrangements.

III. *The Automatic Starter and Primary Switch.*

Factors to be considered for the start of a motor are the starting power, the starting time and the maximum current peaks. By the starting power we mean the product of the voltage and the mean current during start. With DC this represents an actual power, but with AC it must only be regarded as a magnitude which is nearly proportional to the actual power developed. The starting time does not require any further explanation. The current peaks on starting give an indication of the variation of the current during starting, and the relation between the maximum and mean current can be regarded as an index of the smoothness with which the starter runs the motor up to speed.

Every motor requires a certain minimum of starting power and starting time for running up, and these do not in any way depend on the kind of starter or the construction, but on the mechanical conditions such as the starting torque for overcoming the static and rotational friction, and the necessary energy for accelerating the masses in the system. The starting power must be at least sufficiently great for the motor to develop a torque greater than the necessary starting torque, and the starting time must be so long that the mechanical energy given out by the motor during starting reduced by the friction losses will be sufficient to impart the requisite amount of energy to the masses in the system.

It may be stated as a general rule that an automatic starter of a certain type is cheaper the greater the maximum current peak is in relation to the mean current, and the starting power in

relation to that theoretically necessary. As it will be seen immediately that the disadvantages as regards the motor and the supply are greater the greater the starting power and maximum current peak, it follows from this that the choice of a starter must be a compromise between first cost and the troubles to be expected on the supply network when it is used.

A large number of different types of automatic starters have been developed and put into use for pumping equipments. A short description is given below covering those which are most common, and their advantages and drawbacks are given.

Starting Arrangements for Squirrel Cage Motors:

a) *Direct switching on of motors.* For this a primary switch is required, such as a float switch of Asea's type KX or KF, or else a contactor of type AEV. The rush of current on switching on is large, amounting to 5 to 7 times the normal load current. The starting torque is approximately equal to the normal torque. This method can accordingly only be considered for small motors, or in such cases where the supply would not be affected. Reciprocating pumps cannot be started in this manner unless the motors are chosen of particularly ample dimensions.

b) *Star-Delta Starting of motors.* For this method a primary switch is required as in the foregoing case, and an automatic changeover switch for star-delta connecting the stator. The changeover switch is of the 3-pole two-way type. In this manner the maximum rush of current is reduced, and reaches a value about double the normal, but at the same time the starting torque is reduced to about one-third of the normal. The method must accordingly be regarded as less suitable for starting pumps, which, as explained earlier, have a torque which increases as the square of the speed. With Y connection it would accordingly only be possible to reach about 50 % of full speed. The current surge on changing over from this connection to delta can be exceedingly great, unless special arrangements are used. These considerably increase the cost of the automatic installation. If a good start is to be obtained in combination with centrifugal pumps, the motor must be chosen unnecessarily large in relation to the normal power required for pumping.

Fig. 2 shows an automatic changeover switch built by Asea, intended mainly for other service, and in which a thermal device is included. The operating time can be adjusted from 5 to 15 seconds, depending on the time in which it is desired to start the motor.

c) *Automatic Auto-Starters.* In starting with an auto-starter a reduced voltage is applied to the motor (50 to 80 % of the normal). The starting torque of the motor decreases in proportion to the square of the voltage. The most suitable starting voltage is that which gives approximately equal current surges on switching on and on changing over, and in the case of centrifugal pumps this is about 70 to 75 %. The principle is approximately the same as for a hand operated apparatus, and the only change made is to substitute a contactor for the changeover switch with handle. The necessary time is obtained by means of an arrangement which connects full voltage to the motor after a certain time, or by a current limiting relay which operates after the current has fallen to a certain value. Fig. 3 is a diagram showing such an automatic starting arrangement. On starting a circuit is closed from the magnet coil to the contactor 2). This closes and connects the motor 4) on to the low tension terminals. In the next instant contactor 1) closes, throwing the supply voltage on to the starting transformer. The motor starts on the lower voltage. When the time limit relay has finished operating the magnet coil is connected to contactor 2), and the motor is thrown on to the highest voltage. The transformer is entirely disconnected.


Fig. 9. Pumping equipment at the Gothenburg Waterworks at Alelyckan.

The starting torque with this method reaches 50 % of the normal, and

Fig. 10. Automatic pumping equipment at the Vesteras Waterworks, Hessle.

the starting current is from 2 to 3 times the normal.

Like the foregoing method, this may be regarded as less suitable for the automatic starting of centrifugal pumps. As pointed out above, at least 30 to 40 % of the normal torque is required in order to overcome the static friction of the pump, and as additional torque is required for acceleration it is obvious that the margin is very small. In order to be certain that the motor will be able to start under all conditions, it must be selected on the large side, or else the auto-starter voltage must differ by only a small amount from the supply voltage. The advantage gained by the use of a starting apparatus is thus small in comparison with direct switching on.

The methods discussed in a), b) and c) can be used without alteration for motors with self-contained starting winding. Having regard to the maximum current rush at first connection, the use of such a motor affords the advantage that the current on direct switching on is decreased to 4.5 times the normal current, and the starting torque is raised to 2.25 times the normal. By selecting a motor somewhat larger than is required during running, the equipment can be started by direct switching on, without the current at the first instant of starting exceeding the normal running current by more than 100 %.

Starting Arrangements for Slipring Motors.

a) *Hysteresis Starters.* This is a starting arrangement which is used to a considerable extent, and further particulars will be found in Asea's List E II.4. As a primary switch a float switch of type KX or KF is used with small motors for switching the stators direct on to the line; with larger motors or in cases where it is desirable to make the starting gear of small dimensions, contactors are used. The advantage of this type of starter is the absence of all kinds of moving contacts. As regards disadvantages, the somewhat greater phase displacement and lower efficiency than is obtained with a starter which completely short circuits the rotor on the last step may be mentioned. To this must be added a higher price with large outputs, and it is this last point which really determines the use of such starters, and the other two disadvantages can be neglected.

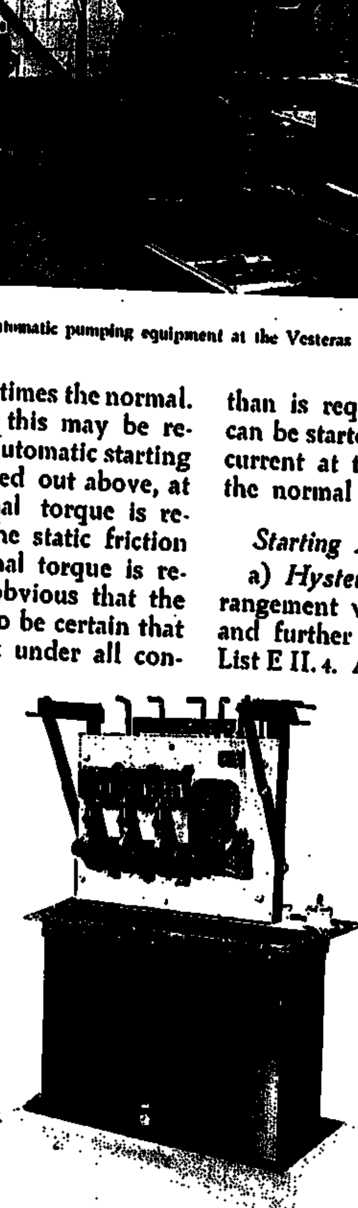


Fig. 11. Oil immersed contactor for a maximum of 100 amperes and 6,000 volts. Contactor lifted out of tank.

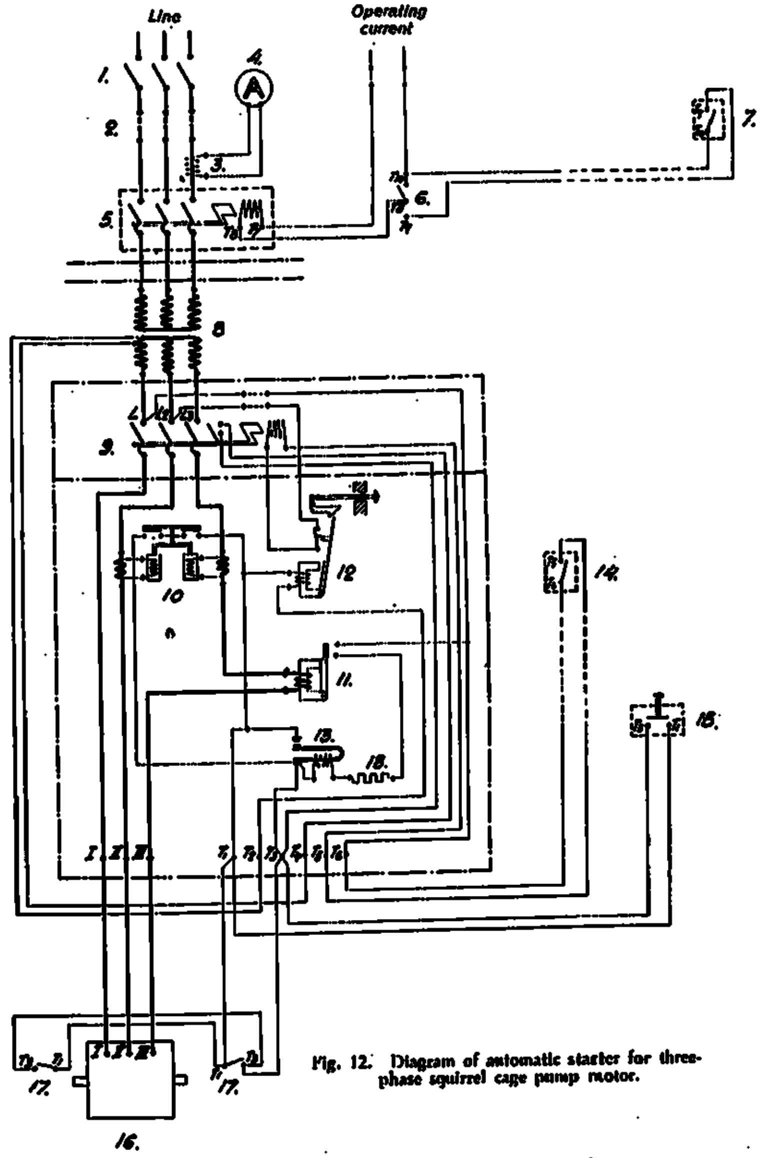


Fig. 12. Diagram of automatic starter for three-phase squirrel cage pump motor.

1. Disconnecting switch.
2. Fuses.
3. Current transformer.
4. Ammeter.
5. Oil immersed contactor for primary circuit.
6. Operating changeover switch.
7. Float contact.
8. Transformer.
9. Contactor for motor protection.
10. Overload relay.
11. Minimum relay.
12. Intermediate relay.
13. Thermo contact.
14. Float contact.
15. Push button.
16. Motor.
17. Thermo contact for pump bearings.
18. Series resistance.

b) *Liquid Starters.* These may be used in certain cases, and are to be noted on account of the particularly smooth starting which they allow. Their disadvantages are partly the large slip (3—5 %) which is allowed when the starter has been fully operated, and the somewhat troublesome amount of attention.

c) *Contactor Starters.* Fig. 5 shows a starter of this type. This resistance is metallic, and the various resistance steps are successively short circuited by a row of contactors. The time interval between the closing of each contactor is determined automatically by a current limiting relay, or by an air damped time relay. Starters working on the contactor principle can be built with as many steps as may be desired. The lower limit is given by the highest allowable current at starting. The upper limit is determined by price considerations. To show how the number of steps affect the question, figures of 6, 7 and 8 have been assumed, which show the starting current with a motor having 2, 3 or 4 contactors in the secondary circuit. If we disregard the first rush of current, which is chiefly determined by the magnetic constants of the circuit, the maximum current reaches respectively 2.1, 1.8 and 1.6 times the normal load current.

d) *Motor operated Starters.* A suitable arrangement for starting slipring motors of large outputs is the employment of motor operated starting gear. While contactor starters are cheaper when a small number of starting steps is acceptable giving abrupt variations in the starting current, the motor operated starter must be regarded as the most suitable for giving a smoother start. All standard starters of types PTSV, PTSO and PTK can be manufactured for motor operation. Fig. 9 shows a starter type PTK at the Gothenburg Waterworks, and fig. 10 shows a starter of type PTSO in the Vesteras Waterworks. (As regards the principle of operation of these starters, we refer to an article on automatic starting gear in our Swedish journal, 1922, No. 4).

The primary switches are common to all the starting apparatus. These connect and disconnect the stator respectively when the motor is to be operated. For low voltages a normal switch of type KX or type KF can be used up to the sizes given in the lists. When these values must be exceeded contactors should be chosen from list VI. 5. These must also be used when any arrangement of distant operation or operation from several positions is desired. With higher voltages (over 550 volts) the normal contactor types are unsuitable, and we must employ oil immersed contactors, which, like oil switches, make use of oil as a medium for break and insulation.

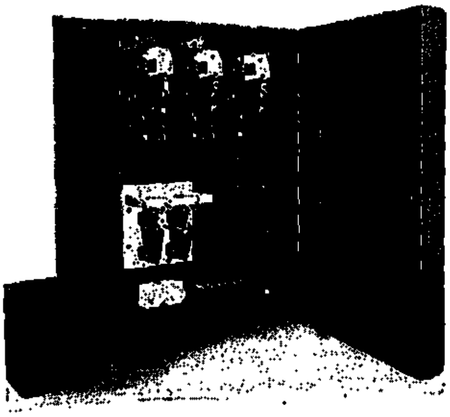


Fig. 13. Automatic DC starter with overload and no-voltage releases, for 15 h.p., 220 volt pump motor.

Fig. 11 shows a switch of this type which can normally be used up to 100 amps. at 6,000 volts.

When high tension current is to be used in a pumping station, it is most satisfactory to arrange the apparatus as shown in the diagram, fig. 12. Here the transformer can be placed in the same position as the pumps, while the contactor (5) is erected in the most suitable place, either in the pumping station or at a distance therefrom. By using the scheme given, we gain a number of advantages. Thus all no load losses in the transformers are avoided. The motor can be wound for low voltage and becomes a standard machine.

Lastly, some mention must be made of arrangements for DC.

a) *Direct switching on.* This can only be used for small motors up to 0.75 h.p. The motors must be considerably over-compounded.

b) *Contactor starters.* This can be designed and used subject to the same limitations as were mentioned for AC. In general it is possible to employ a smaller number of steps, for instance, 2 steps up to 2/3 h.p. and 3 for 10/15 h.p. etc.

c) *Motor operated starters.* Between these and contactor starters a choice must be made on the same basis which was mentioned earlier in connection with AC. Contactor starters are, however, in general considerably cheaper for DC than for AC, and at the same time the limiting current is considerably lower, so that a contactor starter for DC is generally more compact than a motor operated starter.

To simplify the choice between the large number of different types, the table given below can be referred to.

IV. *Operating and Delivery Controlling Apparatus.*

In general the pump is required to work automatically in accordance with the following principle. With a certain pressure or water level the pump must start, and stop again when another predetermined pressure or water level has been reached. As an operating device, in the former case a pressure operated switch or manometer is used, and in the latter case a float switch.

Fig. 14 shows the particularly robust type of pressure operated switch which is manufactured by Asea.

In certain cases circumstances may arise under which the pump must be started by an attendant, *e.g.* at the commencement of the working period, or on the occurrence of an outbreak of fire. If the pump is situated in an out-of the-way position, a good deal of time is wasted in journeys to it and back again. It is, however, possible to arrange for remote control from a convenient position. For this purpose the main circuit can either be closed by hand if the supply line to the pumping station passes the place in question, or electric operation can be arranged for by means of a small relay or push button. In the latter case, however, a special operating circuit to the pump must be run. The number of conductors for operation is in general two.

Another case exists when the pump is to be started at a definite time, and stopped when a certain water level is reached, *etc.* For this purpose an ordinary time switch is used.

There should always be an arrangement which makes it possible to start the pump at the pumping station for purposes of inspection and adjustment. Care must be taken in this connection to prevent any damage arising, for instance through flooding the reservoir. A suitable protection is to arrange a push button which only allows the pump to run as long as it is kept depressed.

Motor type	Squirrel cage AC motor	High starting torque three-phase squirrel cage motor	Slipring AC motor	DC motor
Starter Type:				
1. Direct switching on	Up to 5 h.p.	Up to 10—20 h.p.	—	Up to 1 h.p.
2. Autostarter	5 h.p. to largest sizes	5 h.p. to largest sizes	—	—
3. Hysteresis starter	—	—	5—40 h.p.	—
4. Contactor starter	—	—	5 h.p. to largest sizes	1 h.p. to largest sizes
5. Motor operated starter	—	—	30 h.p. to largest sizes	50 h.p. to largest sizes

It is frequently desirable to be able to start the pump by hand should necessity arise. In general also a stand-by pump is provided. In such cases it is desirable to be able to arrange for the two pumps to run alternately, so that more uniform wear takes place. These requirements can be met quite easily. Fig. 10 shows a control panel for this purpose, with arrangements for connecting a 75 h.p. and a 125 h.p. motor. The system is carried out in such a way that the connecting switches are interlocked with one another so that automatic working cannot be obtained if the switches are not in their proper positions, *i.e.* one pump must always be arranged for normal running, and the other in reserve.

V. *Electric Protective Devices.*

We mentioned earlier (under section I) the breakdowns of the pump and piping system which can damage the plant. As soon as one of these failures occurs the motor must be stopped, in order that the electrical parts may not also suffer damage. To these must be added a number of other protective devices which are made necessary by the nature of the electrical equipment. These include the following:

Overload releases.
No-volt release.
Thermal relays in the bearings.
Release when the pump load fails.
Protection against freezing or seizing up.

The overload release should be of the delayed action type, and the thermal relays of types RW and SBW have been found to work with every satisfaction. Oil damped relays have also been used, but care must be taken, as at particularly low temperatures the oil may freeze. The overload releases protect the electrical equipment against excess current, *e.g.* if the pump seizing up.

The no-voltage protection is intended to disconnect the equipment as soon as the line voltage fails for any reason. The starter must then automatically return to the starting position before a new start can be effected. All the automatic starters described above are equipped in this manner.

The bearings are protected against damage through running hot, by the installation of indicating thermometers or thermo elements *etc.* which stop the equipment as soon as an abnormally high temperature occurs. These parts of the apparatus should be so placed that they do actually come into close contact with the part of the bearing where the danger may occur, *i.e.* the inner surface of the bearing bushes. With electric motors trouble due to hot running of this nature is of very infrequent occurrence. With pumps, however, the outer bearing, *i.e.* the bearing which takes up the end thrust can easily warm up if the cooling water ceases to flow. The contact arrangements which are used are connected to a relay in the electrical system.

Should air enter the pump it will refuse to draw water; this is manifested by the load current decreasing considerably. The pump takes only from 30 to 40 % of the full load current. It is accordingly possible to protect the pump against overheating from this cause by the use of a minimum relay. This relay is provided with damping, *e.g.* by employing a small thermal device so that it is possible to start the pump.

Should it not be possible to run the pump because it has seized up, or because it has frozen up, the motor and starter is protected against damage from excess current by means of a special relay which disconnects the motor if it is prevented from coming up to its full speed for more than about 20 seconds.

Fig. 12 shows a diagram in which all these protective devices are included. The operating current is here taken from the transformer itself, which has extra terminals giving a supply at about 10 volts. This voltage is ample for contact thermometers, and is fully sufficient to operate auxiliary and protective relays.

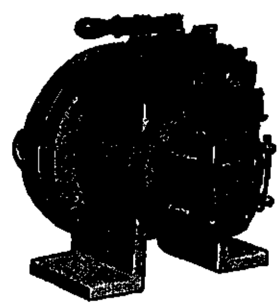
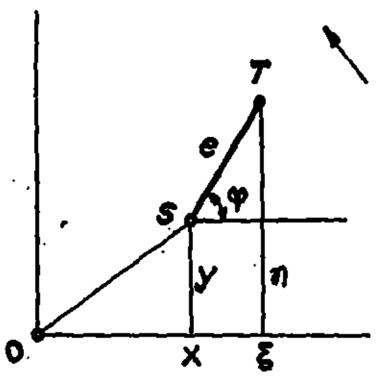


Fig. 14. Pressure operated switch.

BENDING VIBRATIONS IN ROTATING SHAFTS.

This question has received considerable attention in the technical press during the last few years. The fact is that several critical speeds other than the normal have been found experimentally, these speeds being in general in the neighbourhood of half the normal. Attempts to explain these new critical speeds have usually been very complicated. We shall endeavour below to give the reasons for the vibrations in question in the simplest possible manner.



We shall first estimate the ordinary critical speed in the usual manner. Imagine a shaft carried in two bearings and having fixed in the centre a disc having an eccentricity e. T is the centre of gravity of the pulley, S the locus if the shaft centre, and O the point at which the common centre line of the bearings cuts the central plane of the disc. The weight of the shaft is neglected in comparison with that of the disc. The modulus of elasticity of the shaft is called c, the weight of the disc M and the moment of inertia about the centre of gravity J. The resultant external torque, *i.e.* the resultant of the driving and braking torques, is called k. As we do not wish to consider torsional vibrations we can most suitably imagine the driving torque as an electrical torque acting upon the disc which is considered as being the rotor in an electrical machine, and the braking torque as being the windage resistance of the disc. Then no torsion occurs in the shaft. We have

$$M\frac{d^2\xi}{dt^2} = -cx \text{.................} (1)$$

$$M\frac{d^2\eta}{dt^2} = -cy - Mg \text{ ....} (2)$$

$$J\frac{d^2\varphi}{dt^2} = -cx \cdot e\sin\varphi + cy \cdot e\cos\varphi + k \text{......} (3)$$

$$\xi = x + e\cos\varphi \text{ ....} (4)$$

$$\eta = y + e\sin\varphi \text{ ....} (5)$$

Expressing x and y in equations (1) and (2) in terms of ξ and η, with the help of equations (4) and (5) we obtain, if at the same time Mg is neglected, which is for example perfectly correct for a vertical shaft:

$$M\frac{d^2\xi}{dt^2} + c\,\xi = c \cdot e\cos\varphi \text{...........} (6)$$

$$M\frac{d^2\eta}{dt^2} + c\eta = c \cdot e\sin\varphi \text{...........} (7)$$

$$J\frac{d^2\varphi}{dt^2} = c \cdot e\,(\eta\cos\varphi - \xi\sin\varphi) + k \text{ ....} (8)$$

We assume $k = 0$ and make a trial putting $\varphi = \omega t$, *i.e.* a constant rotational speed, and investigate if under these assumptions equations (6) to (8) can be satisfied.

The solution of (6) if we assume ξ and $\frac{d\xi}{dt} = 0$ for $t = 0$ is

$$\xi = \frac{e}{1 - \frac{M}{c}\omega^2}\cos\omega t - \frac{e}{1 - \frac{M}{c}\omega^2}\cos t\sqrt{\frac{c}{M}} \text{...} (9)$$

Actually there is always some damping, and oscillations accordingly disappear, except under resonance conditions, so that after a short time we obtain

$$\xi = \frac{e}{1 - \frac{M}{c}\omega^2}\cos\omega t \text{ ....} (10)$$

corresponding to

$$\eta = \frac{e}{1 - \frac{M}{c}\omega^2}\sin\omega t \text{ ....} (10\,a)$$

further $\varphi = \omega t$...............................(11)

It is seen that if $k = 0$ equation (8) is also satisfied, since both right and left hand couples are zero. Equations (10 a) and (11) are thus capable of exact solution for the case of a vertical shaft where the effect of gravity disappears and where the driving torque is constant and equal to the braking torque.

It will be seen that there is only one critical speed when

$$\omega = \omega_k = \sqrt{\frac{c}{M}} \text{ ....} (12)$$

In this case the solutions for ξ and η in accordance with equations (10) and (11) do not hold good, and we must use equation (9). In accordance with this ξ has for $\omega = \omega_k$ the form $\infty - \infty$, but by investigating this expression in the usual manner we obtain

$$\xi = \frac{1}{2}\, e\, \omega t \sin \omega t \quad \ldots\ldots\ldots\ldots\ldots (13)$$
$$\omega = \omega_k$$

In the same way we obtain

$$\eta = -\frac{1}{2}\, e\, \omega t \cos \omega t \ldots\ldots\ldots\ldots (14)$$
$$\omega = \omega_k$$

For each revolution the expression is thus increased by πe. It should be noted that equation (8) with $k = 0$ is not satisfied by ξ and η in accordance with equations (13) and (14). This signifies that constant angular velocity $\omega = \omega_k$ cannot be maintained with constant driving torque. For the torque equation to be satisfied with standard $\omega = \omega_k$, the external torque must on the contrary vary in a definite manner which can easily be obtained from equations (8) and equations (13) and (14). Actually when the external torque is constant or nearly constant, the variation in the point of resonance is somewhat different. If the resulting external torque is practically zero, for example, if the shaft runs freely on ball bearings in a vacuum, the expression for the point of resonance even without damping, is unlimited. The energy for the oscillations must accordingly come from the flywheel, so that the speed is quickly brought down below the critical value.

So far we have only obtained the normal critical speed.

The conditions are quite different if we allow small fluctuations in the angular velocity ω caused by variations in the driving torque, or, as we shall see later on, by the weight of an axle supported horizontally.

We assume

$$\frac{d\varphi}{dt} = \omega + \Delta\omega \cos n\,\omega t \quad \ldots\ldots\ldots\ldots (15)$$

where ω is the constant mean speed, from which

$$\varphi = \omega t + \frac{\Delta\omega}{n} \sin n\,\omega t \quad \ldots\ldots\ldots\ldots (16)$$

$$\cos\varphi = \cos\omega t \cdot \cos\left(\frac{\Delta\omega}{n}\sin n\,\omega t\right) -$$
$$- \sin\omega t \cdot \sin\left(\frac{\Delta\omega}{n}\sin n\,\omega t\right)$$

When $\frac{\Delta\omega}{n}\sin n\,\omega t$ is a small angle we can, with good approximation, put

$$\cos\varphi = \cos\omega t - \frac{\Delta\omega}{n}\sin n\,\omega t \cdot \sin\omega t$$

$$\cos\varphi = \cos\omega t - \frac{\Delta\omega}{2n}\Big[\cos(n-1)\,\omega t - \cos(n+1)\,\omega t\Big] \quad (17)$$

Equation (6) is thus altered to

$$M\frac{d^2\xi}{dt^2} + c\xi = c\cdot e\cos\omega t - \frac{c\cdot e\,\Delta\omega}{2n}\cos(n-1)\,\omega t +$$
$$+ \frac{c\cdot e\,\Delta\omega}{2n}\cos(n+1)\,\omega t \quad \ldots\ldots\ldots (18)$$

Analogously with equation (10) we obtain the stationary condition

$$\xi = \frac{e}{1-\frac{M}{c}\omega^2}\cos\omega t - \frac{\Delta\omega}{2n}\,\frac{e}{1-\frac{M}{c}(n-1)^2\omega^2}\cos(n-1)\omega t +$$
$$+ \frac{\Delta\omega}{2n}\,\frac{e}{1-\frac{M}{c}(n+1)^2\omega^2}\cos(n+1)\,\omega t \ldots (19)$$

Corresponding equations are obtained for η.

It is seen that there are three critical speeds when

$$\omega = \sqrt{\frac{c}{M}} = \omega_k \qquad \omega = \frac{\omega_k}{|n-1|} \qquad \omega = \frac{\omega_k}{n+1} \qquad (20)$$

If ω changes once in each revolution, *i.e.* $n = 1$, we obtain a new critical speed

$$\omega = \frac{1}{2}\omega_k$$

If $n = 2$ $\quad \omega = \frac{1}{3}\omega_k$

$n = 4$ $\quad \omega = \frac{1}{3}\omega_k$ and $\frac{1}{5}\omega_k$

$n = \frac{1}{2}$ $\quad \omega = \frac{2}{3}\omega_k$ and $2\,\omega_k$

In reciprocating machine drives where the torque changes periodically these critical speeds can be worthy of attention, and also in the case of single-phase machines with variable electrical torque. A flexible coupling, when the shafts are not properly lined up, can also give rise to variable torque, and thus to these new critical speeds.

Returning now to the case of a shaft supported horizontally with a resultant torque equal to zero, we will now take the weight into consideration. In each revolution the weight M is lifted a distance $2e$. The potential energy is thus altered during each revolution by an amount of $\pm eMg$. A corresponding alteration accordingly exists in the kinetic energy

thus $\frac{1}{2}J(\omega + \Delta\omega)^2 - \frac{1}{2}J\omega^2 = eMg$

or $\quad \Delta\omega = \frac{eMg}{\omega J} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (21)$

When $n = 1$ here the new critical speed caused by the weight is $\frac{1}{2}\omega_k$.

By assigning numerical values corresponding to normal cases it can be shown that the varia-

tions in angular velocity due to the weight are in general exceedingly small.

An exact investigation of the change in the point of resonance naturally gives rise to greater difficulties with variable torque than with constant torque. As in the former case, where we assumed that at the point of resonance the torque varied so that the angular velocity was maintained constant, we can here also assume that the torque varies so that the angular velocity at the point of resonance is obliged to remain at the assumed value. It is then easy by analogy to obtain by equation (13) from equation (18) an expression for ξ at the point of resonance with variable angular velocity. Comparison between the speed at which the amplitude of the expression increases at the actual point of resonance with constant angular velocity and at the new points of resonance with measurable values of speed variations, show now that the increase in this last case takes place considerably slower, so that these new critical speeds do not show resonance peaks to nearly the same extent. This specially affects the influence of the weight, which in general can be entirely neglected. The effect of cyclic irregularity of a reciprocating machine is accordingly of much greater importance.

Ragnar Liljeblad.

IMATRA POWER UNDERTAKING, FINLAND.

One of the largest industrial undertakings in Northern Europe at present is the electrification of the Imatra Falls. These are situated on the Vuoksen River. This river has a large number of falls in its length of 162 km, and as a commencement the large fall at Imatra,

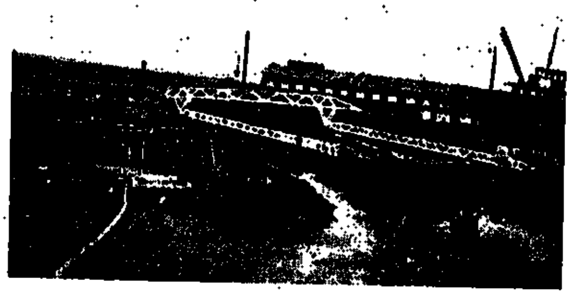


Fig. 1.

together with some smaller falls lying higher up, have been developed for a head of 24 metres and a quantity which, it is estimated, will reach 80 cubic metres per second after the outfall has been regulated, and which is to be undertaken in the future.

At the present time the power station is being constructed for four units of 24,000 kVA with a power factor of 0.8, and of which three only have been ordered at present. The generators are wound for 11 kV, and this is transformed up to 120 kV. Two main transmission lines are supplied at this pressure, viz. one having a length of 52 km to Viborg, and one with a total length of about 517 km for Western Finland, which passes through Villmanstrand to Hikia, where it divides into two branches, one being taken to Abo and one to Helsingfors and Karis.

The transmission line, which has a double set of conductors, is erected on iron lattice towers of particularly interesting design. Figs. 1 and 2 which are reproduced from photographs of the first tower constructed, give a good idea of the appearance of these special poles and of the ingenious manner in which they are raised into position.

The work in connection with the Imatra electrification has been carried out by the Finnish State Waterfalls Board.

Asea has obtained orders for a very large proportion of the electrical equipment.

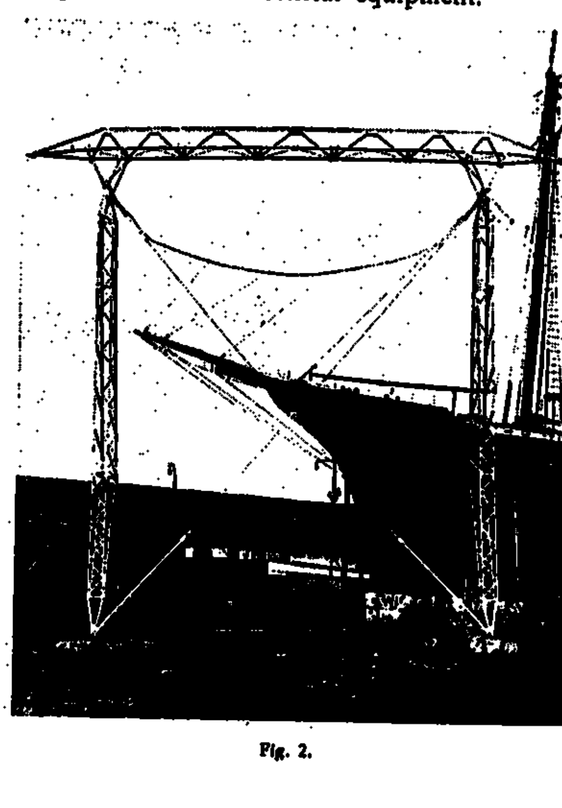
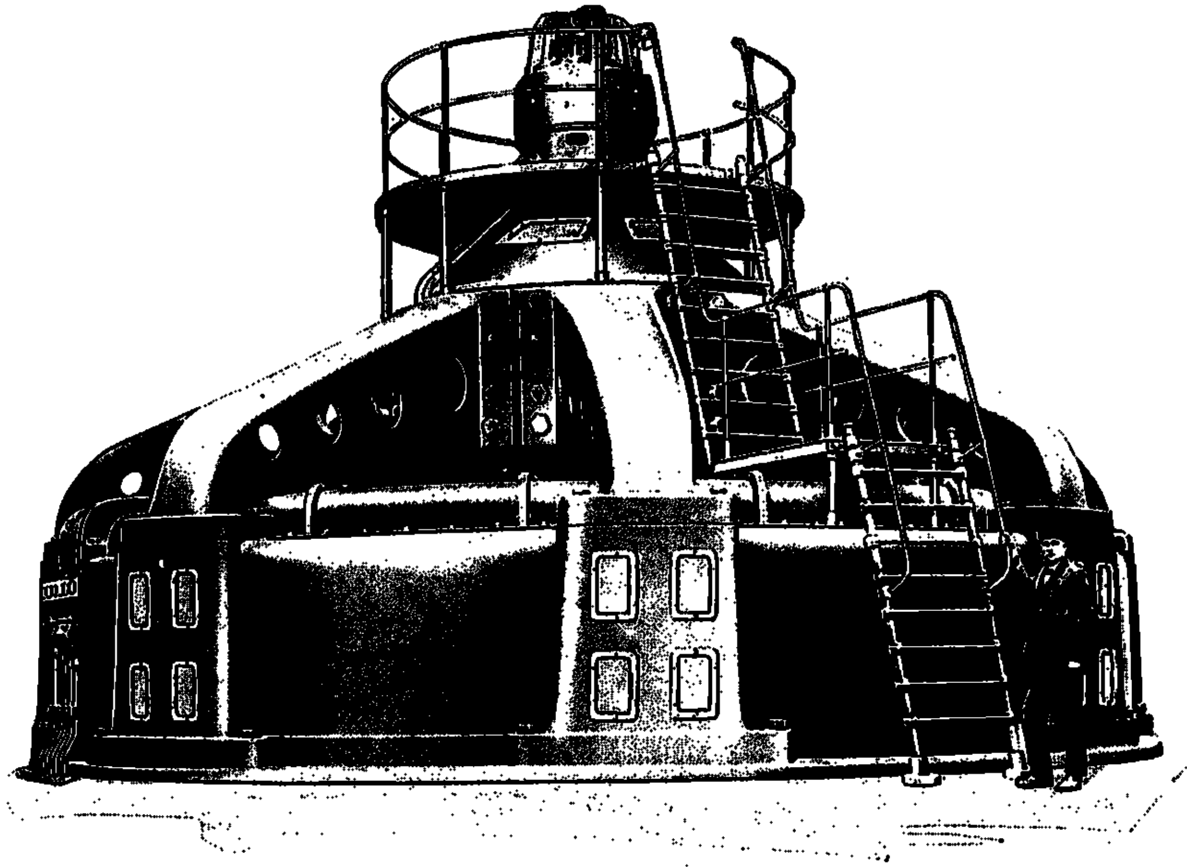


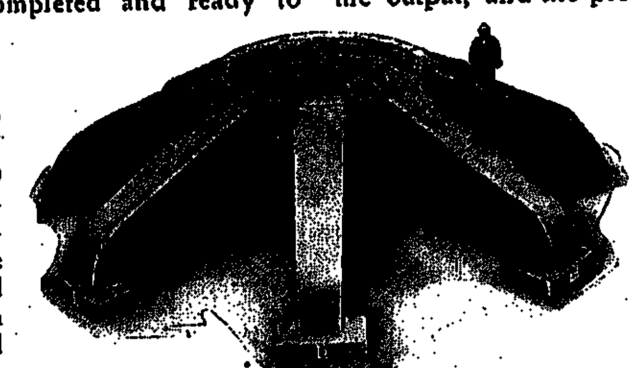
Fig. 2.

LILLA EDET SWEDISH STATE HYDRO ELECTRIC STATION.



No. 2 generator completed.

Asea is at present engaged in completing the order received for machinery for the fifth large Swedish State Power Station, which has been built at Lilla Edet on the Gota Elv (River), and when finished will be one of the most remarkable hydro electric stations in the whole world. The first of the large three-phase generators was delivered last year: the illustration above is a view of the second machine, while the third generator is now completed and ready to leave the shops in Vesteras. All of these generators are designed for an output of 10,000 kVA at 62.5 r.p.m., 25 cycles, 10,000—11,000 volts, and a power factor of 0.7. These machines are probably the largest of their kind which have so far been built in Europe, and some idea of the dimensions can be gathered from the photographs reproduced. The diameter of the stator at the floor level is 9,450 mm and the height from the floor to the highest point is 6,300 mm, while the lowest point of the machine extends to 2,150 mm under this level. Each generator weighs 350 tons complete, of which about 325 tons is represented by iron, and the remainder chiefly by copper. The very great weight in relation to the output, and the proportion existing between the various materials is due to the exceptionally low speed which has in its turn been determined by the low height of fall which is available. For the same reason the water turbines which drive the generators are of colossal size — they are without doubt the largest in the world which have so far been produced —



Upper arm-cross and supporting bearing for one of the Lilla Edet generators.

and as their rotating parts are supported from the upper arm-cross of the generators — one arm of which will be noted immediately above the man's head in the photograph — this has also been made of exceptional strength. The supporting bearing, manufactured by Asea, which is contained in the centre of the arm-cross and is supported by it, is designed to carry the exceptionally heavy load of 550 tons, which is in part made up by the rotating parts of the generator itself and the rotating parts of the turbine and the shaft, and in part by the exceptionally heavy thrust due to the masses and reaction of the water on the turbine wheel.

The power from these three generators, 30,000 kVA, will be used to a large extent to meet the load due to the electrification of the main western railway line. The power for this railway will thus be supplied from Asea generators, taken to Asea transformers through Asea apparatus and Asea motor converters, for use in motors which will also have been manufactured by Asea.

THE M/S "GRIPSHOLM".

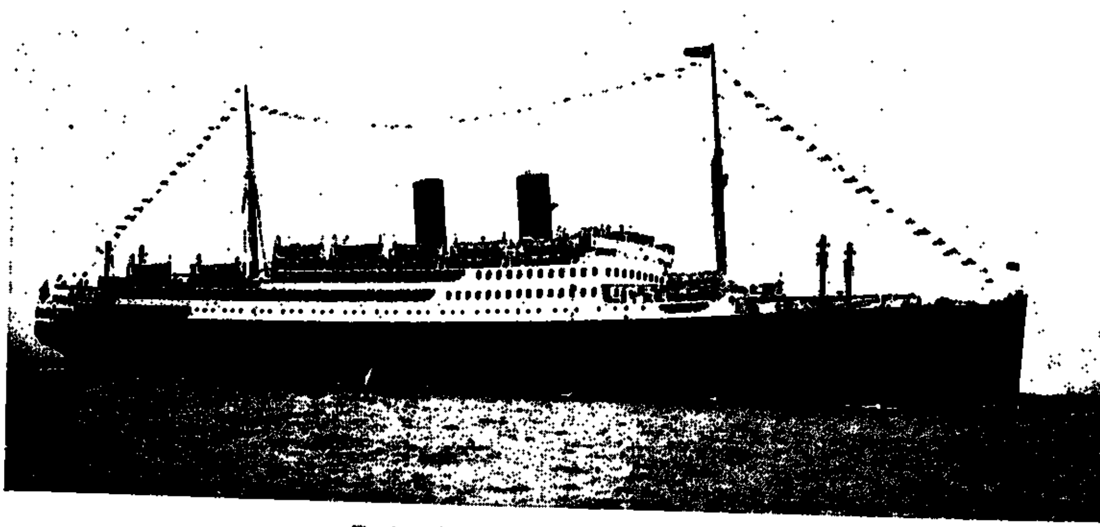


Fig. 1. M/S "Gripsholm" arrives in Gothenburg.

The new motor ship "Gripsholm" for the Swedish America Line is the largest and most luxurious Atlantic liner flying the flag of Sweden. This ship was built at Messrs. Armstrong Whitworth's yard on the Tyne, and may be said to commence a new chapter in the history of transatlantic traffic: steam and smoke have disappeared since the "Gripsholm" is propelled by Diesel engines, and as these are the largest which have so far been constructed, on this account also the vessel has attracted widespread interest.

The ship measures 574½ ft. in length, with a beam of 74 ft., and is driven by two double-acting 4-cycle directly reversible Diesel engines, which during normal running have a speed of 125 r.p.m., and together develop approximately 17,000 h.p.

The voyage between Gothenburg and New York will be accomplished in about 8 days.

Speed and seaworthiness have been combined in the "Gripsholm", and all the most modern developments in the shipbuilding art have been embodied. The space which is occupied by the propelling machinery is considerably less in a motor ship than in a steam driven vessel, and the room available for passengers is on this account much extended, the promenade deck in particular being unusually large.

Machinery manufactured by Asea has been employed to a considerable extent in connection with the equipment of the ship, and all the necessary electrical machines for lighting, passenger and goods lifts, refrigerators, ventilating installation, ballast and bilge pumps, thermotank, etc., comprising about 80 DC motors in sizes ranging from ½ up to 35 kW together with their accessories, have been supplied by Asea.

Probably however, as regards material deli-

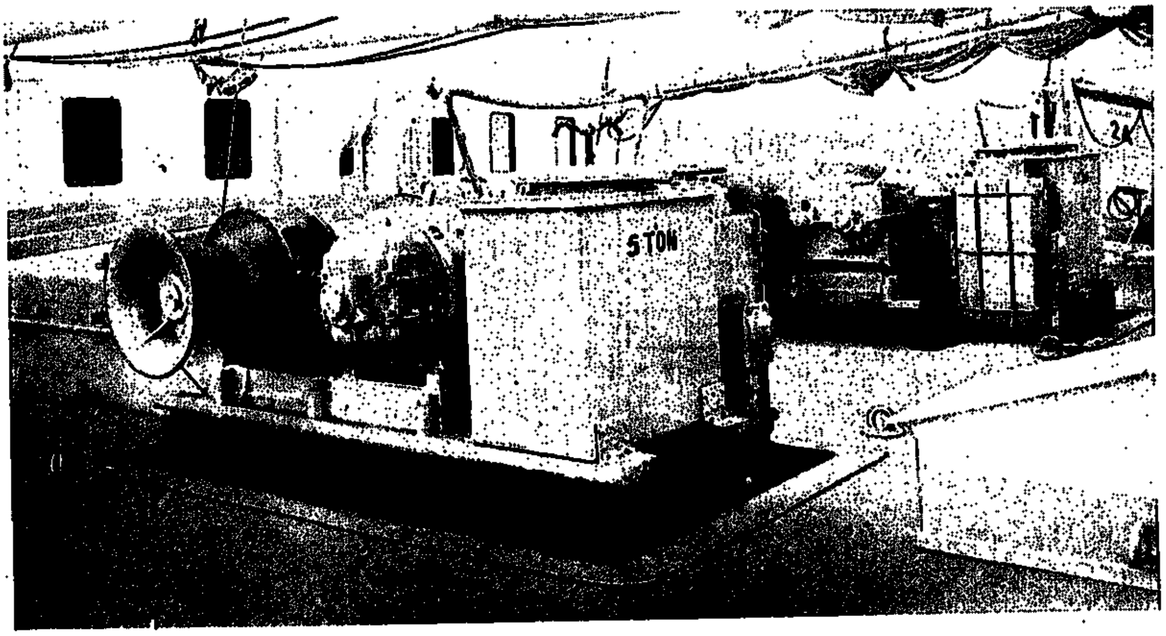


Fig. 2. A view on deck showing the two 5-ton winches.

vered by Asea, the electric winches will be found most worthy of attention, both from the point of view of ordinary travellers and also engineers, and a few particulars of these will be given.

On the "Gripsholm" are installed ten 3-ton winches, each furnished with 20 in. cable drums, two 16 in. winch heads, and 2-speed gear for lifting speeds of 120 and 240 ft. per minute with 3 and $1^1/_2$ ton loads respectively. In addition there are two 5-ton winches, also provided with 20 in. cable drums and two 16 in. winch heads, the 2-speed gear in this case being arranged for 80 and 200 ft. per minute with 5 and 2 ton loads.

All the winches are furnished with 35 h.p. motors wound for 220 volt DC supply.

These winches, which are mounted on the deck chiefly in the neighbourhood of the hatches, are all of an entirely new type, and having regard to the particularly long lifts which are in question, they have been arranged with the exceptionally high speeds mentioned above so as to make possible the greatest speed practicable in loading and unloading.

The winches are of exceptionally heavy design both as regards the mechanical and electrical equipment, and full regard has been given to the difficult working conditions under which they will have to operate on board. The electrical parts is of a special construction which we have developed for this class of machinery, and motors, as well as brake magnets and operating gear, are completely enclosed by water-tight covers, although easily accessible for maintenance and oiling. The mechanical construction is entirely new, and was developed to meet the special needs of the case. Spur gears are used, the large wheels being of cast steel and the pinions cut from special steel, all the gearing having machine cut teeth. All the gears run in oil and are cased in heavy totally enclosed oiltight cast iron housings.

These winches are operated in the simplest possible manner, and any deck hand is able to work them without experience and special instruction.

Vesteras 1926, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

ALLMANNA SVENSKA ELEKTRISKA A.B.
VESTERAS — SWEDEN

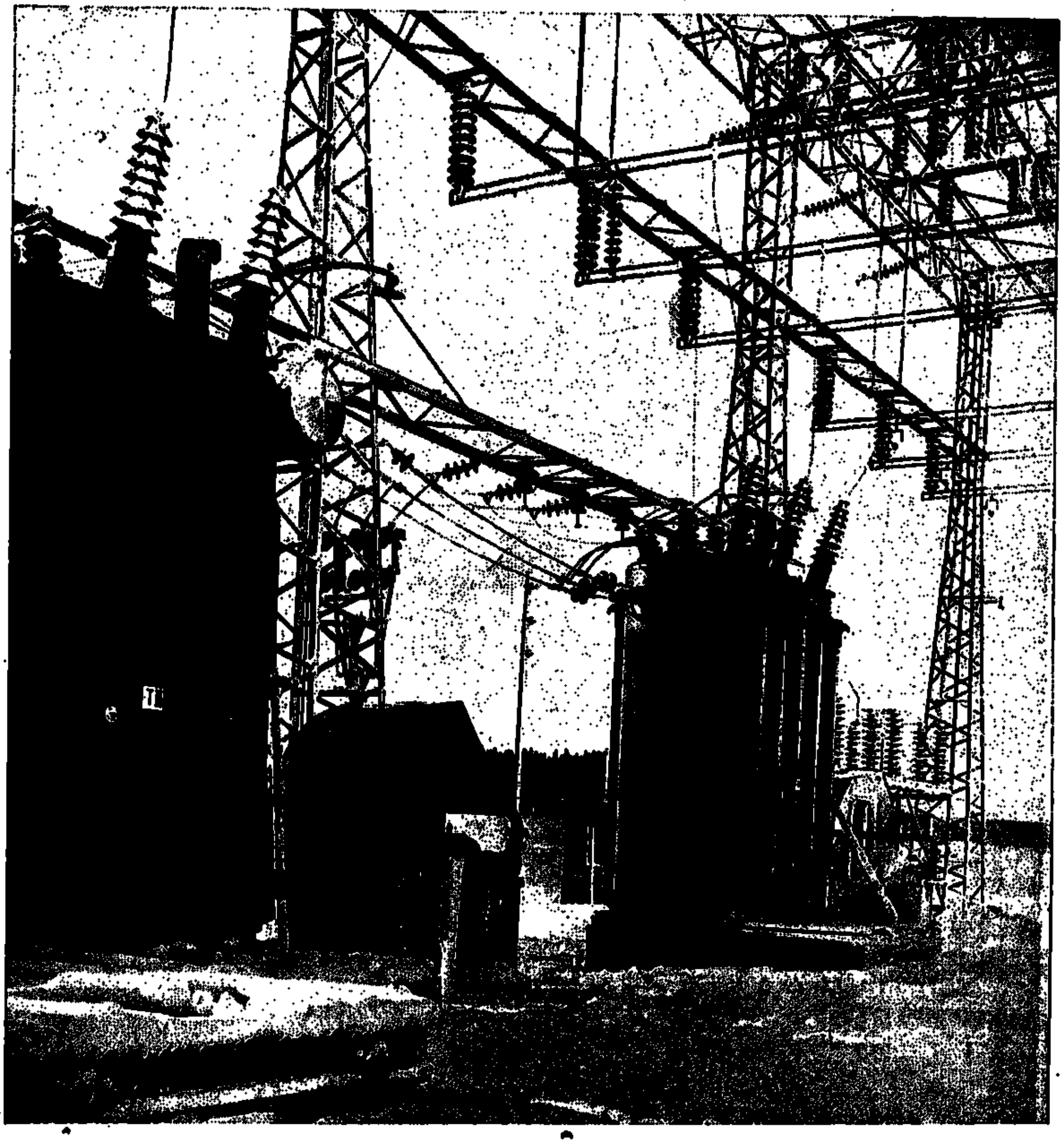
SWEDISH GENERAL ELECTRIC LTD
5, CHANCERY LANE—LONDON

MONTHLY REVIEW

VOL. III
1926

All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesteras, Sweden.

AUGUST
No. 8



10,000 kVA three-phase transformers, 123/77/6.3 kV, with forced air coolers erected in the outdoor substation of the Royal Waterfalls Board at Hallsberg, Sweden.

PRESSURE REGULATION ON POWER NETWORKS USING STEP BY STEP REGULATORS.

The more extended and complicated a power network becomes, the more difficult is the pressure regulation problem. The voltage regulation which can be obtained by adjusting the fields of the generators is insufficient, and other means must be adopted. By introducing synchronous machines at important points in the network, and making use of them for regulating the power factor, it is often possible to obtain very good pressure regulation. In cases where this method is not possible or is unsuitable, or when it is desired to supplement the arrangement, a very satisfactory regulation can be obtained by altering the ratio of the transformers connected to the supply, or by making use of separate voltage regulating units consisting of induction regulators or transformers capable of regulation. This article deals with the possibilities of voltage regulation obtainable by the use of transformers with adjustable ratio.

A study of the conditions of voltage regulation on a network will show that four different kinds of voltage adjustment may be necessary. In the first place regulation is required due to the increase in the average yearly load or due to the variation in the load during any given year. This may be called *seasonal regulation.* Secondly regulation is required due to the variation in load over the twentyfour hours — *daily regulation*, and thirdly we have to take into account load variations of short duration — *short period regulation.* Lastly when two or more power networks are interconnected and it is desired to have the voltages of the networks as far as possible independent of one another, pressure regulation is required at the points of interconnection — *parallel regulation.* It should be observed that the expression short period regulation does not refer to a regulation which exactly follows the load variations. Such regulation in most cases is not necessary, as the variations in load which occur are of such a character that it will be sufficient if the regulator acts on voltage variations with a duration of a few seconds.

We refer to fig. 1, which is a schematic diagram of a power network. From the power station one or more feeders are run to the secondary transformer substations S. From these a number of secondary feeders are taken to various tertiary transformer stations T, and from these again to transformer stations U for small distributing districts or separate consumers. The object of voltage regulation on such a system is to keep the pressure constant at the consumers' terminals. As long as the supply system is lightly loaded the voltage drops are small and no voltage regulation is necessary. As the load increases the need for regulation arises, but at the outset the requirements are limited to raising the voltage of the main distributors. To meet this requirement seasonal regulation must be adopted. If the load increases further, so that the voltage variations due to load alteration during the day become a nuisance, then the regulating arrangement must be supplemented with devices for daily regulation. Lastly when the load increases to such an extent that loads imposed for a shorter time get troublesome, short period regulation must be used.

As the load existing on a distribution network becomes more evenly distributed as the distance from the consumers increases, it follows that the voltage variations due to short period loads are less evident in the neighbourhood of the power station. The daily regulation can also be levelled off to a considerable degree, due to the fact that different kinds of load occur at different times. Arrangements for regulating the voltage should therefore be placed at different points, depending on the nature of the regulation. Seasonal regulation, which is only required a few times during the year, can be effected at the power station and at the secondary and tertiary substations. This regulation can be done by hand while the transformers are not on load. Daily regulation, which must be adjusted several times per day, can either be done at the power station or at the secondary transformer stations. This regulation can also be carried out by hand, but must be done on load. The controlls can be located in the transformer stations, or remote

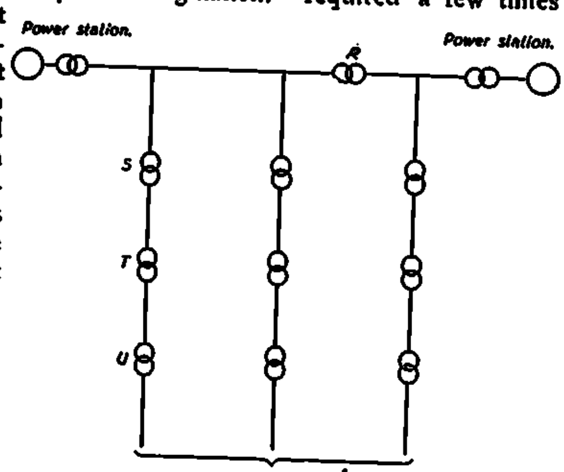


Fig. 1. Diagram of power network.

control can be adopted. In cases where there are no attendants available in the neighbourhood, the control can be made completely automatic. Short period regulation should be arranged for as close to the consumers' premises as possible, for example in the tertiary transformer substations. This regulation must be effected under load, and should be fully automatic.

The voltage steps are chosen of different magnitude, depending on the kind of voltage regulation in question. In general the short period regulation should be as far as possible continuous, or at any rate carried out in small steps so that it is not noticeable at the lamps on the circuit. As regards daily regulation, which is only in operation a few times during the day, the voltage steps can be chosen greater; and this applies still more to seasonal regulation. In normal cases voltage steps for short period regulation should be taken between 1 and 3 %, for daily regulation between 3 and 5 %, and for seasonal regulation between 5 and 10 %.

Regulation for parallel operation, the object of which is to make possible the transfer of energy from one power system to another without this transfer of power making the voltage regulation on the different networks dependent upon one another, is chiefly in the nature of power factor regulation. This voltage regulation is most suitably carried out on the transformer or transformers which connect the two systems. This can be carried out by hand, by remote control, or fully automatically, depending on the conditions. The steps in the regulation and the range of regulation can be chosen with considerable latitude. In general, the system of regulation greatly depends on the working conditions desired, and no general rules can be given. An example showing the problems which occur in conjunction with this kind of regulation has been dealt with in a foregoing article in this paper (March 1926, page 40. Automatic regulating equipment for the Randers—Aarhus transmission scheme, Denmark), to which interested readers are referred.

As we have mentioned before, voltage regulation is carried out by transformers through the alteration of their ratio. This alteration is obtained by arranging extra tappings on the respective windings. These extra tappings can be taken up to some position above the upper yoke of the transformer, so that reconnection can be effected after lifting the transformer out of the tank, or by making use of hand holes in the cover. They can also be carried through the cover and changed by hand outside the transformer, or else altered by a tapping switch placed inside the tank and operated from outside. In all these cases reconnection must be effected with the transformer disconnected from the supply. It has been pointed out already in a foregoing article in this paper (Sept. 1924, page 85), that the arrangement with extra tappings carried up to a reconnecting device placed above the upper yoke is only suitable where the transformer can be partly lifted out of the tank, so that this arrangement should only be used when the ratio of the transformer can be fixed when it is installed. That is to say, the method should only be used in cases were repeated alteration in the voltage ratio is not likely to occur. For requirements of real voltage regulation, the transformers should be provided with some arrangement for easier reconnection, *i.e.* with a tapping switch or with extra terminals taken through the cover. As reconnection in all these cases can only be effected with the transformer switched off, they are methods of voltage regulation only suitable for seasonal regulation.

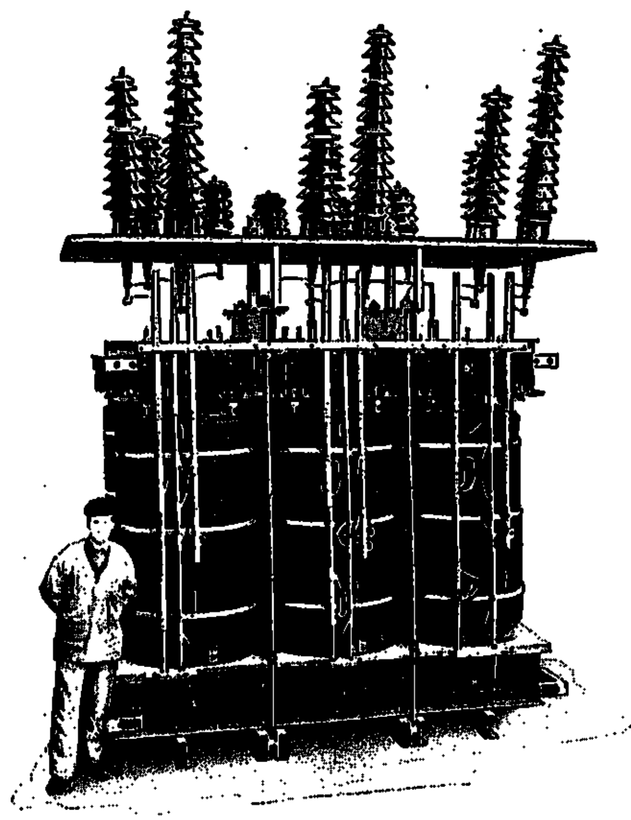


Fig. 2. 6,000 kVA three-phase transformer, 46/61, 58, 55, 52, 49 kV, 50 cycles, Y/Y connected, with regulating tappings on the H.T. winding.

For daily regulation, which must be carried out on load, an entirely different reconnecting arrangement is required. For this Asea employs so-called "ratio regulators", which were designed about 20 years ago. With the help of

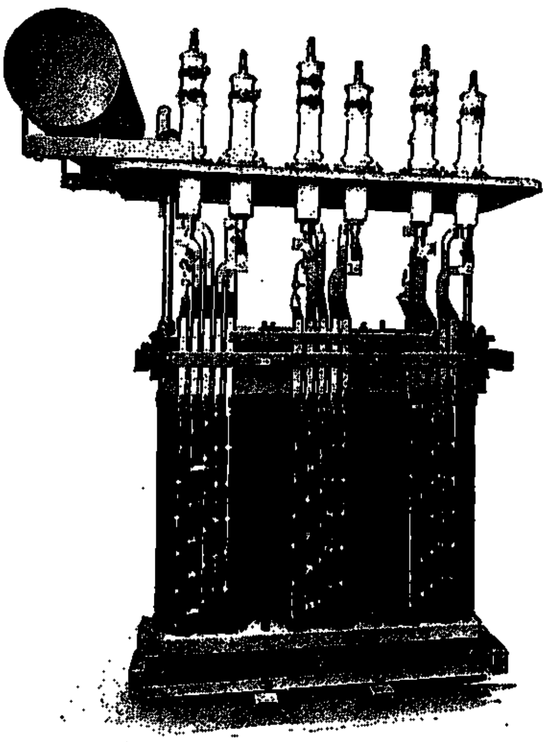


Fig. 3. 3,000 kVA three-phase regulating transformer, 10/10 ± 2.5, 5, 7.5, 10 % kV, 50 cycles, Y/auto-connected.

these the ratio of transformers can be altered during operation without breaking the current or introducing any discontinuity in the voltage. The ratio regulators, which were originally built for regulating the voltage of furnace transformers, are now designed in a number of different types for various purposes, and it is the employment of this apparatus which makes possible the use of step by step regulation as a satisfactory method. In principle they are similar to end-cell regulators as used for accumulator batteries in that the change from one tapping to the next is first made through an ohmic resistance, which is connected between the two tappings on the transformer between which the change is to be made. The resistance is afterwards connected in series with the line and finally short circuited. By operating the ratio regulator with a motor, electric remote control can be obtained, and by replacing the operating switch or push button necessary for remote control by a contact relay it is possible to obtain full automatic operation. A regulating arrangement so equipped can be used as a short period regulator.

Voltage regulation is carried out, as before described, by altering the ratio of the transformers on the supply network, or in separate regulating transformers. In the former case the extra terminals for altering the ratio can be arranged on either the high or low tension winding, depending on which winding is found to give the simplest and most reliable arrangement. The selection also depends upon which winding has the most suitable current and voltage for the ratio regulator. In general, the high tension winding on a standard power transformer is found to be most suitable for the arrangement of extra tappings, because this winding commonly lies outside relatively to the core. Voltage regulation with tappings on the main transformer forms the cheapest solution of the problem, the only cost being that of the ratio regulator and of arranging the extra tappings. On the other hand constructional difficulties often limit the number of tappings, making the steps larger than might be desirable for the purpose in question.

The separate regulating transformers are built as auto transformers and their output in per cent of the transmitted power is equal to half the range of voltage regulation in per cent of the mean voltage. They can be connected to the high tension or low tension side of the main transformer; by making use of two transformers — one series transformer and one regulating transformer — it is possible, if necessary, to adjust current and voltage for the extra tappings and ratio regulators to suitable values. As a separate regulating transformer is in most cases a more expensive arrangement than the use of extra tappings for the same range of regulation and the same voltage on a transformer suitable for other service, it is usually cheaper to arrange for regulation on the main transformer. In cases where one can arrange a separate regulating unit for considerably lower voltage than that for which a ratio regulator and tappings on the corresponding normal transformer must be provided, the separate regulating unit will however be found cheaper.

The advantages of the separate regulating unit are most obvious when we compare the different types from the point of view of reliability and with regard to their ability to meet varying load conditions. In both cases the vital parts consist of transformers, tappings and ratio regulators. The different details should accordingly, if designed for the same voltage, not differ from the reliability standpoint, except that a regulating transformer, being a series apparatus, is exposed to much larger mechanical stresses, if on short circuits they must take up the full line voltage. The main transformer, however, usually limit the currents to safe values for the regulating transformer, except possibly for short-circuits within the transformer, so that the

weakness of the regulating transformer in this respect is of small practical importance. The advantages of the separate regulating transformer from the point of view of reliability consist partly of the fact that the regulating parts in most cases can be designed for comparatively low voltage, and partly that they can be easily disconnected when a breakdown takes place, and working continued without interruption, although with depreciated voltage conditions. The greatest advantage with the separate regulating units is, however, that they give a power network equipped with such units great adaptability to altered power requirements and power distribution. A relatively large network can, for example, be designed for three or four different voltages, a high tension V_1 for long lines, a medium V_2 and one or more low voltages V_3 and V_4. At different points on the network the regulating requirements usually vary. This means that if voltage regulation is carried out by tappings on the main transformer, making for example a change from V_1 to V_2, a transformer must be used at each such point of regulation.

If it is required to change the transformers round on account of increased load or other alterations on the network, this cannot always be done in the most satisfactory way, partly as transformers designed in a different manner cannot always operate in parallel, and partly as transformers which are furnished for certain requirements of regulation do not always meet the requirements existing on other points of the network. The whole system is accordingly inflexible, and cannot be adapted to meet changed conditions arising due to development.

If, however, all the main transformers are designed for example for changing from V_1 to V_2 without regulating tappings, or with only such tappings as are required for seasonal regulation, *e.g.* ± 5 % arranged for changing with the transformers dead, with the same ratios, short circuit voltages and system of connections, so that they can all operate in parallel, and if all regulation during working is effected by separate regulating units properly designed for the various points at which they are installed, then a considerably more flexible system is obtained. The main transformers are also in this way simpler and cheaper. The regulating units, which represent a comparatively small part of the cost of the transformations, are of course designed for the regulating requirements at the respective points, but are easily removable and can be better suited to altered conditions. The main transformers can be moved without any alteration, so as to be in the most suitable places. Such a manner of arranging transformers may be dearer in the first instance than arranging regulation on the main transformers, but in the long run there is a considerable advantage, since new equipments can be made more adaptable to extensions and alterations in the network, and above all, as it is not necessary to lay out new plant in an unsuitable manner in order to make the best use of existing transformers. If the same principle is carried through all the transformers, that is to say for those also which are required for voltages V_3 and V_4, we obtain a power network which not only can be adapted to altered conditions, but which is also reliable, particularly as the question of spares can be dealt with in a simple and cheap manner.

Induction regulators may be directly compared with the separate regulating units described above. In power networks they were used earlier than step-by-step regulators and are often considered superior to these because a continuous voltage regulation can be obtained. This advantage is, however, only apparent as long as the induction regulators are not constructed for rapid

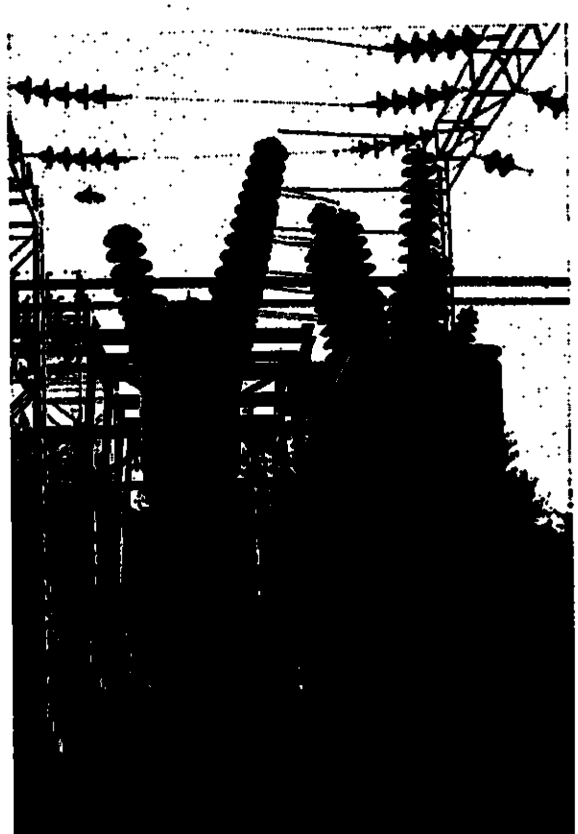


Fig. 4. Power transformer with ratio regulator, 55 kV working voltage, erected outdoors.

operation. As the voltage variations are very quick, the induction regulators must follow all the variations automatically in order that their continuous pressure regulation may be made full use of. This is, however, not possible, partly because the moving parts of the induction regulators have considerable inertia, and on this account cannot follow the rapid variations, and partly because the operating relays — contact voltmeters or contact relays — which automatically operate the induction regulators, cannot be made to work on voltage variations less than from 1—2 %. On account of this fact induction regulators do not give better results than might be obtained with step regulation. If the induction regulators are controlled with operating gear or by hand, the possibility of following the voltage variations are still poorer, so that continuity in the voltage regulation with induction regulators exhibits small advantages over step regulation in transformers with ratio regulators. The advantage which induction regulators have relative to step regulators is that the former can be left in any position whatever without risk of resistance or contacts burning out. If a ratio regulator is left in the mid position due to failure of the operating gear, *i.e.* with the intermediate resistance carrying current, this will be burnt out after a longer or shorter time unless the whole of the regulating apparatus is made dead. By careful construction and design of the ratio regulators, it is however possible to reduce this risk to a minimum. If the driving motor which automatically works the ratio regulator is rendered dead when in an intermediate position, the intermediate resistance can also be damaged. The risk of this is, however, possibly even less, since the chance of the voltage failing during the short time (about one second) in which the resistance is connected, is so small. Under all conditions it is easy to protect against burning out of the resistance by installing a thermal relay which trips the circuit breaker of the regulating unit if the resistance becomes too warm. All our automatically operated ratio regulators of modern design are provided with such relays.

The disadvantages of induction regulators relative to step regulators are partly that they are found to be more expensive, less reliable, have higher no load losses and reactance, and make the plant more complicated if the voltage exceeds 3—6 000 volts. (Induction regulators cannot be connected directly to the network, but must be connected through one or two transformers). If double induction regulators are not used, the additional voltage is in phase with the line voltage only in the highest and lowest positions, and when the component of additional voltage in phase with the line voltage is zero, the terminal voltage of the induction regulator is not zero. The result of this is that the induction regulator cannot be disconnected on load, but the line must first be made dead so that the induction regulator is not directly short circuited.

THE ASEA RATIO REGULATORS.

The first ratio regulators made by Asea were intended for regulating the voltage of transformers used for electric furnaces. The working conditions made it necessary to be able to regulate the voltage supplied to the furnace within wide limits. As in most cases the furnace equipments were supplied from a power network having a constant voltage, this voltage regulation could only be effected by altering the ratio of the transformers employed. In order to simplify the changes in connections required on this account, ratio regulators were designed for operating on load. These, which were known as type UR regulators, were the only types constructed for a number of years, but some time ago a number of existing disadvantages began to be troublesome, and the arrangement was completely redesigned. The result of this was that two new types were developed, one a universal type for use with voltages up to 33 kV, and one a more special arrangement for voltages between 33 and 77 kV. Both these types have now been in use for some years, and have been found to meet the conditions in a very satisfactory manner. As these have not been described before, we shall give in the following a few details of their construction, and at the same time make a comparison between them and the well-known older types.

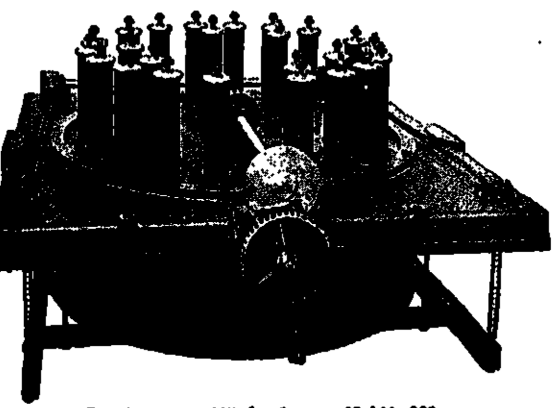


Fig. 1. Regulator type UR for 5 steps, 22 kV, 200 amperes, exterior view.

All these ratio regulators consist in principle of a reconnecting arrangement, by which different tappings on a transformer can be conneted successively to the incoming line or to other terminals on the transformer without breaking either current or voltage.

The transfer from one tapping *a* to the next in order *b* is effected by first of all connecting an ohmic resistance between the two tappings. In the next instant the connection between, for example, *a* and the line is broken without the connection between the resistance and the line being removed. The resistance is then connected between tapping *b* and the line, and is accordingly in series. In the next instant the resistance is short circuited and the line connected directly to tapping *b*. Thus, in this manner, the reconnection from tapping *a* to *b* has been made without breaking current or voltage, and without short circuiting any part of the transformer windings during the process. The ohmic resistance is dimensioned so that the current through it will not exceed the normal current of the winding when it is connected between two tappings on the transformer.

Regulators of type UR have already been fully described in the foregoing article, so that in the present case we shall only refer to their disadvantages. The general appearance is shown in figs. 1 and 2. It will be seen that the contact surfaces are fixed direct to the leading through insulators These are arranged in a circle, which makes the arrangement of the leads between the ratio regulator and the transformer somewhat difficult. Another disadvantage is that the intermediate resistances are separately mounted, thus not only taking up considerable room, but also further complicating the layout of the conductors. The circular form of the contact surfaces makes it necessary for the whole ratio regulator to be of large dimensions if the working voltage or the voltage difference between respective tappings is high. The adjustment of the contact brushes and their contact fingers and contact surfaces has also been found to be somewhat awkward on account of the large diameter of the circular contact pieces, and also due to their horizontal position underneath the baseplate of the regulator.

In order to prevent burning at the brushes and contact surfaces, a number of UR type regulators for severe operating conditions have been made with separate break arrangements by means of which the current is closed and interrupted. These, which were provided with contact pieces of normal knife pattern, were mounted on one side of the ratio regulator, easily accessible for inspection and operated from the same shaft as the ratio regulator itself. In this way practically all need for attention to the actual ratio regulator with changing of contacts and brushes disappears, and the necessary attendance is greatly simplified. The appearance of such a UR type regulator with separate break arrangement can be gathered from fig. 3. One advantage of these older type regulators is that they

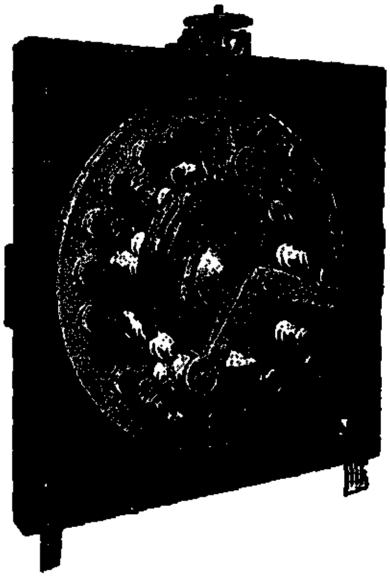


Fig. 2. Regulator type UR for 5 steps, 22 kV, 200 amperes, internal view.

are relatively cheap. This fact accounts for their continued use in cases where there is plenty of room, where working voltage and current is low, in cases where working is not in any way forced, and where it is above all essential to employ an inexpensive regulating arrangement.

In the construction of the new ratio regulators we have endeavoured as much as possible to do away with the disadvantages in the UR type regulators enumerated above. Special attention has been given to arranging the leading through insulators in such a way that a simple arrangement of connections can be obtained, and to embodying the intermediate resistance with the regulator while arranging that all moving parts are accessible for replacement and adjustment, while at the same time constructing the ratio regulator so that it can easily be furnished with a separate break when necessary. Fig. 4 shows the first arrangement of the new ratio regulators for use up to 33 kV, and fig. 5 is a connection diagram for it when used in conjunction with a separate regulating transformer for ± adjustment. It will be clear from these illustrations that the ratio regulator consists in this case of 6 smaller regulator parts, each of which has a separate break arrangement. By suitably combining these parts a ratio regulator is obtained which takes up relatively small space, and at the same time is easily accessible for adjustment and attention. From fig. 4 it will be seen that the leading through insulators are arranged in two rows, one for the incoming and outgoing lines, and the other for connecting the tappings of the transformer. These last leading through insulators are placed also so that they are exactly opposite to the terminals on the transformer to which they are to be connected, so that an exceedingly simple conductor system is obtained. The intermediate resistances are placed under the couplers and are thus immersed in oil, so that their dimensions can be very small.

The operating arrangement, which is made particularly robust, consists of a horizontal shaft by which the different parts of the regulator are operated in correct order. By the use of ball bearings at suitable places, and by careful design of the whole operating system, friction and unnecessary stresses are obviated, so that very small amount of power is necessary for working the ratio regulator.

The brushes for the main contacts are made from tempered copper and bronze laminations sufficiently strong to withstand deformation by any short circuit current which may pass through the ratio regulator. As the regulators are provided with separate breaking arrangements, no make and break of the current takes place at these brushes. They are not accordingly subjected to any particular wear. For smaller currents, and when working is less forced, the separate break arrangement can be dispensed with and the main contacts constructed with easily renewable sparking contacts, so that even in this case there is little tendency for wearing or burning to occur at the main contact brushes. The separate breaking arrangements are constructed like standard oil immersed changeover switches with heavy contacts which can make and break any current to be expected without damage.

In the construction of the newest types of these ratio regulators, special attention has been given to standardisation as well as to the production of gear adaptable to different conditions. The three-phase ratio regulators are accordingly assembled from 3 separate ratio regulator elements, one for each phase, and provided with separate baseplates and oil tanks, united only by the rigid couplings between the horizontal operating shafts and by the common framework upon which the whole is erected.

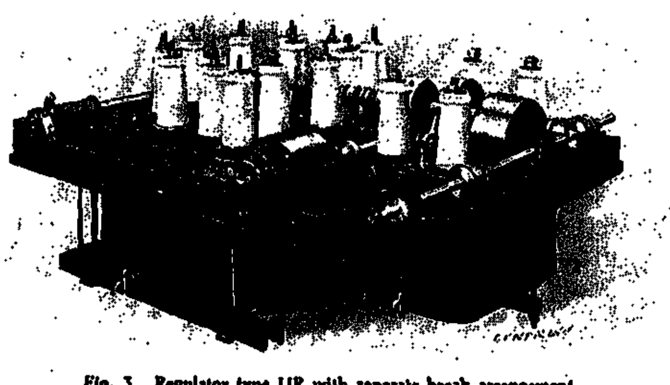


Fig. 3. Regulator type UR with separate break arrangement, 10 kV working voltage, 200 amperes.

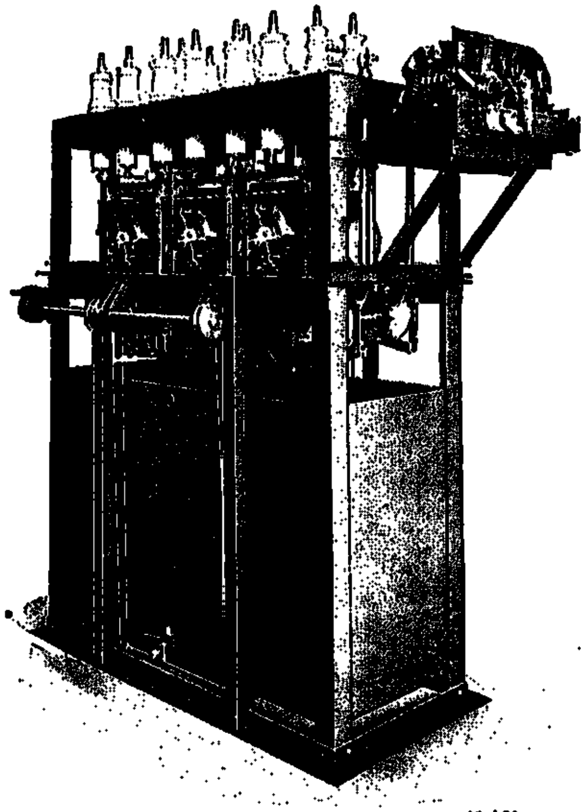


Fig. 4. Ratio regulator for ± regulation, 8 steps, 10 kV, 200 amperes, electrically remote controlled.

For two-phase ratio regulators 2 such elements are used, and for single-phase only one. As a stand-by for a 3 or 2-phase ratio regulator it is thus possible to use one regulator element. In the most complete arrangement each element is provided with 2 regulator parts, together with separate breaking arrangements and intermediate resistance. They can be used for up to 8 regulating steps (9 different voltages) with ± regulation and for a maximum current strength of 200 amps. (A type suitable for currents up to 350 amps. has also been constructed). By connecting 2 coupler sections in parallel the elements can be used for 4 regulating steps (5 voltages) and for up to 400 amps. By leaving out one complete regulator part, a ratio regulator element is obtained for 4 steps and a maximum current of 200 amps. By leaving out the separate breaking arrangement and using sparking contacts on the main contact brushes, a type is obtained for lower currents (about 50 amps.) and less forced working. Lastly, if the intermediate resistance is removed, together with separate breaking arrangements, a type is obtained which is suitable for reconnection with the system dead. From the above it will be clear that this type of ratio regulator is of very general application, and by using it in connection with suitably designed transformers it can be used for practically every requirement of regulation likely to arise. They are somewhat more expensive than our older types, but the advantages more than outweigh the increased cost.

The ratio regulators are furnished for erection indoors or outdoors, and for hand operation, electric remote control or for fully automatic control. In the latter case it is an essential requirement that they are constructed with separate breaks, as otherwise the automatic working would by degrees damage the main contacts. As regards the design for various arrangements of operation, this will be referred to in the following.

The appearance of the ratio regulators for high voltages can be gathered from figs. 6 and 7, the diagram of connections being in accordance with fig. 8. These ratio regulators are an entirely new departure to the type described above. They consist chiefly of a number of contacts in oil, operated in suitable order by eccentrics on a common operating shaft. They are built up from one regulator element per phase joined only by the operating shaft and the supporting framework. The leading through insulators are mounted on the upper supporting plate, and this also carries the bearings for the operating shaft and necessary levers. The contacts themselves are mounted on a separate panel which is fixed to the supporting plate with insulated rods. Under the panel which carries the contacts the intermediate resistances are lastly

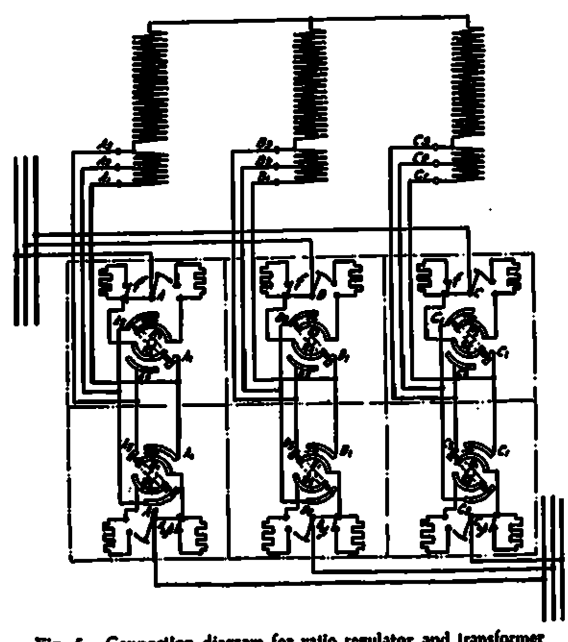


Fig. 5. Connection diagram for ratio regulator and transformer for ± regulation, 4 steps.

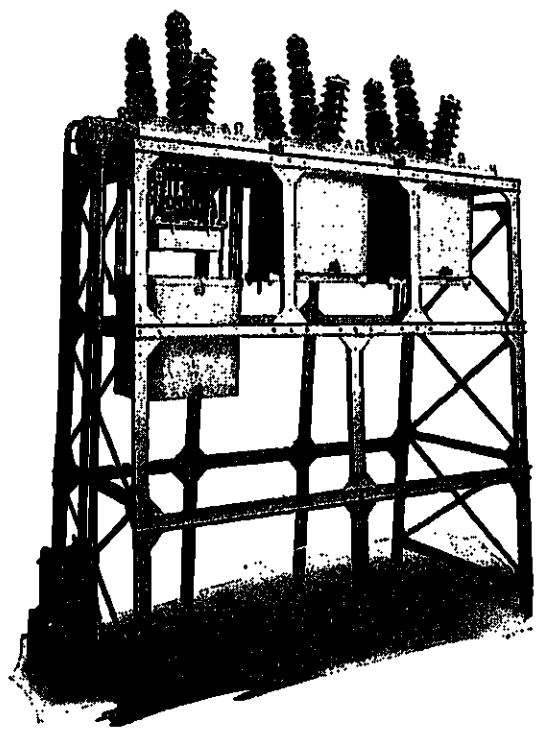


Fig. 6. Ratio regulator for 4 steps, 66 kV working voltage, outdoor pattern.

mounted. The contacts are operated by rods of insulating material connected to levers which are raised and lowered by the eccentrics on the horizontal operating shaft. These ratio regulators are designed for up to 4 regulating steps (5 voltages): each element has one contactor for every step, and two for operating the intermediate resistance. All making and breaking is carried out by the contacts themselves, for which reason these are very amply dimensioned. The contact fingers are provided with springs and arranged in the usual manner, so that when making and breaking a rolling action takes place between the contacts. The contacts are constructed for up to 200 amps. normal current.

The leading through insulators of the regulators, which consist of double or triple concentric condenser type bushings, are arranged so as to be opposite to the insulators on the transformer to which they are to be connected. In order to simplify the erection of the connecting leads, the ratio regulator can be mounted upon framework of such a height that the upper supporting plate is on a level with the cover of the transformer. The operation of the ratio regulator is carried out from the ground level by means of a vertical shaft which drives the main operating shaft of the regulator through a bevel gear. The whole of the operating mechanism is made very strong, and carefully manufactured so as to work in an absolutely reliable manner. No loose links or chains which might bind or ride over their sprockets are used in the device.

As mentioned before, high tension ratio regulators are built with a maximum of 4 regulating steps. All live parts are insulated from earth and from the operating mechanism for full working voltage, and insulation of similar strength is used between phases. The regulators can accordingly be used in combination either with auto-transformers or power transformers of normal design, having tappings brought out through the main terminal and taken either from the centre of the windings or from the neutral point. They can be erected indoors or outdoors, and are manufactured for hand operation, electric remote control, or complete automatic control.

A disadvantage of the ratio regulators just described is that they require a relatively large amount of room and a large number of leading through insulators if the number of regulating steps is high. It would appear to be more simple to embody the ratio regulator with the transformer, and such regulating arrangements have actually been constructed. A requirement for correct technical design with such a combination is that the ratio regulator must be provided with separate break, and this must be placed outside the transformer tank so that the oil in the transformer cannot mix with the oil in which the breaks take place. On this account the number of leading through insulators is not reduced to such a great extent as would be imagined at first sight. The floor space taken is much reduced, but this is at the cost of raising the height of the unit. In most cases this does not cause difficulty, especially in the case of outdoor substations, but transport troubles are soon encountered. The transformers become so high that they cannot be transported to site without entirely dismantling them, and it is also difficult to shift them in the

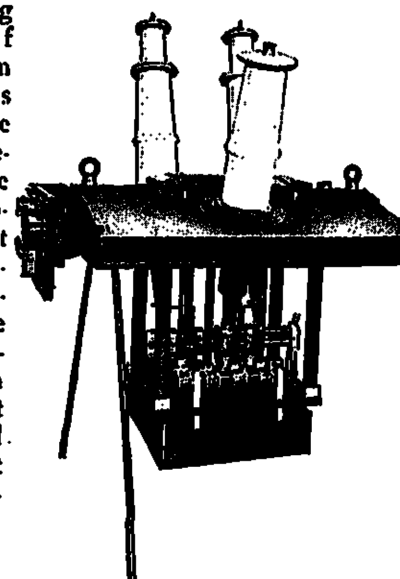


Fig. 7. One phase of 55 kV ratio regulator, 3 steps, indoor pattern.

transformer station. Another reason why ratio regulator combined in the transformer are not a very suitable arrangement, is that the nature of ratio regulators and transformers differs very widely indeed. The transformer has, practically speaking, no moving parts, and requires a very small amount of attention. It is only necessary to test the quality and condition of the oil regularly, and transformers in some cases are not touched for years. A ratio regulator which has a large number of moving parts requires regular inspection, and must be so arranged that all moving parts and contacts are easily accessible. If the ratio regulator and transformer are combined, it is necessary not only to disconnect the transformers entirely from the line when the ratio regulator is inspected, but also partly to dismantle it, which may be exceedingly troublesome.

A ratio regulator external to a transformer can be quickly disconnected should a breakdown take place, and the supply can be continued provisionally, certainly without the ratio regulator, but not without the transformer, which would be the case if transformer and regulator were combined together. In one case it is justifiable to combine the regulator and transformer, namely when they form together a separate regulating apparatus without any other function. In this case, however, as the transformer is connected as a booster, and is thus

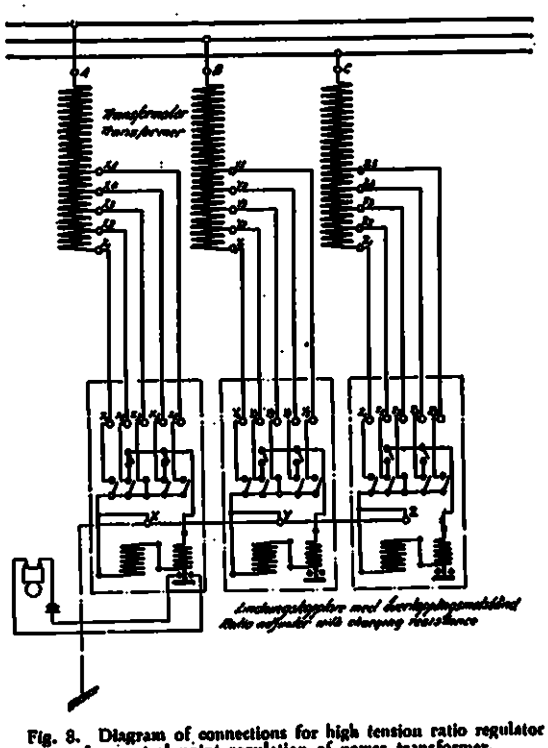


Fig. 8. Diagram of connections for high tension ratio regulator for neutral point regulation of power transformer.

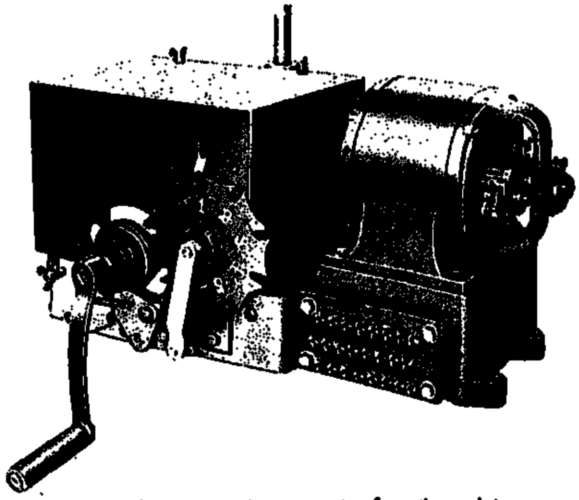


Fig. 9. Electric operating apparatus for ratio regulator.

small relative to the power which passes through it, the transformer will usually be so small that building the regulator together with it does not give any great reduction in space. In general, for the reasons given above, it is not advisable to combine the transformer and ratio regulator.

For operating the ratio regulator, it is provided with a handle or handwheel, or with a sprocket mounted direct on the operating shaft. By a special ratchet arrangement the running positions are determined, and when it is moved an indicator which is mechanically coupled to it shows by means of figures the position of the regulator. If the regulator is erected in such a position that operation cannot be carried out direct at its own level, the operating shaft is furnished with a bevel gear and a specially extended shaft which is carried down to the operating position. Chains should not be used, as they have a great tendency to increase in length, and owing to this it can happen that a regulator may be left in an intermediate position due to backlash. For remote control the ratio regulator is provided with an electric motor which drives the operating shaft through a reduction gear. The motor is worked from a relay or from a double push button, so arranged that the motor can be set in motion in either direction. The appearance of an electric operating arrangement can be gathered from fig. 9. This is provided with auxiliary contacts and switches, arranged so that the regulator moves only through one regulating step each time the operating circuit is closed, and so that the regulator cannot be operated beyond its end position, and so as to ensure that a movement giving one regulating step once started will be completed

if the current through the operating switch is broken, or if it is later changed for regulation to some other position. For indicating the position of the regulator, signal lamps are used, which are connected through a small switch driven from the operating shaft. In cases where operation is to be carried out from a relatively long distance, regulation can be effected from the reading of a voltmeter, and leads for the signal lamps need not be taken all the way to the operating position.

With fully automatic regulation at constant voltage, operation is carried out with the driving arrangement described above, but the operating switch is replaced by a contact relay supplied from the line on which the voltage is to be kept constant. As soon as the voltage departs by a certain percentage from the constant value, the contact relay closes the operating circuit and sets in motion the driving motor in one direction or the other. The closeness with which the voltage can be kept constant with an automatic ratio regulator is dependent on the sensitivity of the contact relays, as well as on the magnitude of the voltage steps on the regulating transformer. The former can reach 1 to 1½ % variation in voltage, and the latter should be chosen for the conditions under consideration. It is necessary, however, to consider the magnitude of the voltage step and the sensitivity of the contact relay in relation to one another. In order that a voltage variation which is of such magnitude that it will just operate the contact relay may be compensated for by only one regulating step, this should be at least equal to the magnitude of the voltage variation, *i.e.* equal to the sensitivity of the contact relay, and the regulating step should not be greater than approximately 1.5 times the sensitivity of the contact relay, otherwise there is a risk of the ratio regulator hunting. Accordingly, if a voltage step of 2 % on the transformer is chosen, a contact relay must be installed which has a voltage variation of from 1.3 to 2 %.

With automatic operation it is possible to make a regulating unit which will give a voltage increasing with the load on the network by placing in series with the pressure transformer which supplied the contact relay an adjustable ohmic and inductive resistance, which is in turn connected in the secondary circuit of a current transformer placed in the outgoing lines. The voltage drop in the compensating resistance can then be balanced so as to be exactly similar to the voltage drop in the outgoing line to the point at which the voltage is to be kept constant. By suitably connecting and dimensioning the compensating resistance the automatic regulating arrangement can also be arranged to control the division of the reactive power between two different networks running in parallel. The appearance of a panel arranged with operating relay, contact relay, push buttons, compensators etc. is shown by fig. 10.

In order to obtain the greatest dependability, automatically operated ratio regulators should always be furnished with a wheel for hand operation and an operating relay for electric remote control, and a ratio regulator for remote control only with a handwheel for hand operation. In order to protect the ratio regulator against stopping in an intermediate position and burning out the intermediate resistance, this should be provided with a signalling contact which closes the circuit and gives a signal during the time that the ratio regulator is between two steps. As an extra protection, distant and automatically operated ratio regulators are also fitted with thermal relays which close a contact if the temperature of the oil in the regulator exceeds a certain value. These relays release the main circuit breakers for the regulating transformer, and the whole unit is rendered dead.

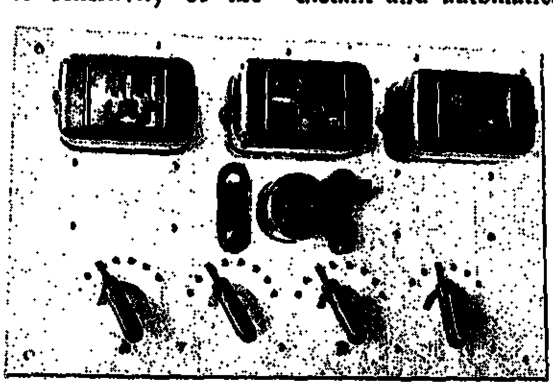


Fig. 10. Operating relays etc. for automatic pressure regulation.

VARIOUS METHODS OF ARRANGING REGULATING STEPS ON TRANSFORMERS.

In general it has been found that requirements as regards regulation are exceedingly variable. They can, however, be reduced to a few simple cases. In the following we give the most usual systems of connection which occur when voltage

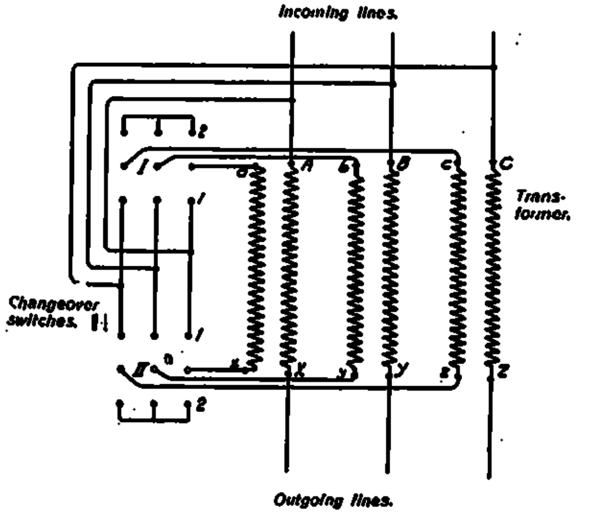


Fig. 1. Diagram of voltage regulating unit consisting of a series transformer and two 2-way switches.

regulation is arranged with a transformer in conjunction with a ratio regulator or other tapping arrangement. With these connections and with variations of them, nearly all regulating requirements can be met.

When a cheap regulating arrangement for comparatively simple requirements is desired, an arrangement in accordance with fig. 1 can be used. This consists of one series transformer and two 3-pole 2-way switches. One winding of the transformer AX, BY, CZ is connected in series with the line, and the other winding ax, by, cz is connected in Y to the line through the changeover switches I and II. When switch I is in position 1, and II in position 2, the series transformer gives, for example, a positive additional voltage. If the changeover switch I is placed in position 2, the secondary of the transformer is short circuited and acts as a short circuited current transformer. Under these conditions there exists only the normal voltage drop, and the voltage at the incoming and outgoing lines is practically the same. If then the changeover switch II is placed in position 1, the additional voltage is negative and the outgoing voltage is lower than the incoming. With this arrangement accordingly we obtain ± regulation in 2 steps. This arrangement should only be made use of with hand operation or electric remote control, as otherwise the operating arrangement would become complicated and less reliable. If no intermediate resistance is arranged in the changeover switches, so that changing from one position to another is carried out without breaking the current, the arrangement should not be used for high voltages, since during the instant of switching over a pressure reaching about double the normal is induced in the magnetising winding ax, by, cz with full current in the series winding. Without intermediate resistance accordingly the arrangement should not be used for higher working voltages than up to about 1 500 volts. With an intermediate resistance it can be used up to 6 000 or 10 000 volts. The changeover switches must be designed so that they can only be left either in position 1 or 2, and not in any intermediate position, as in such case there would be a risk of damaging the core of the series transformer by heating, since the transformer would act as a current transformer with open secondary winding. The arrangement has the advantages, in addition to simplicity and cheapness, that the changeover switches themselves are not in series with the line current, and accordingly only require to be of such dimensions as to be capable of dealing with the current in the magnetising winding, and no incorrect connections can be made by operating these switches.

For voltage regulation by means of extra tappings on a standard power transformer, three different methods can be used. The extra tappings can be arranged either at the termi-

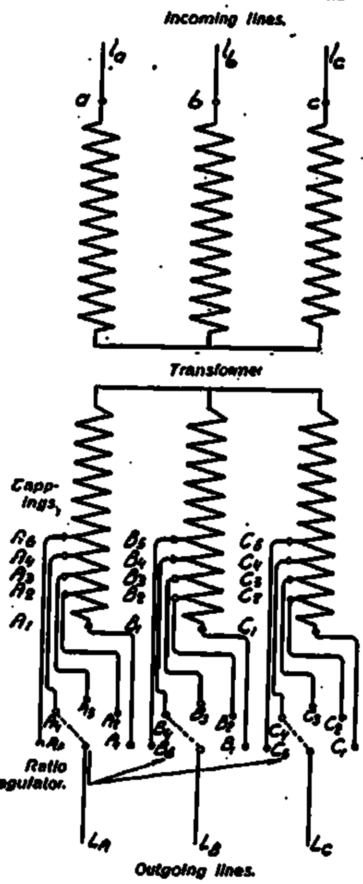


Fig. 2. Diagram of standard power transformer with regulating tappings at the terminal ends of the winding.

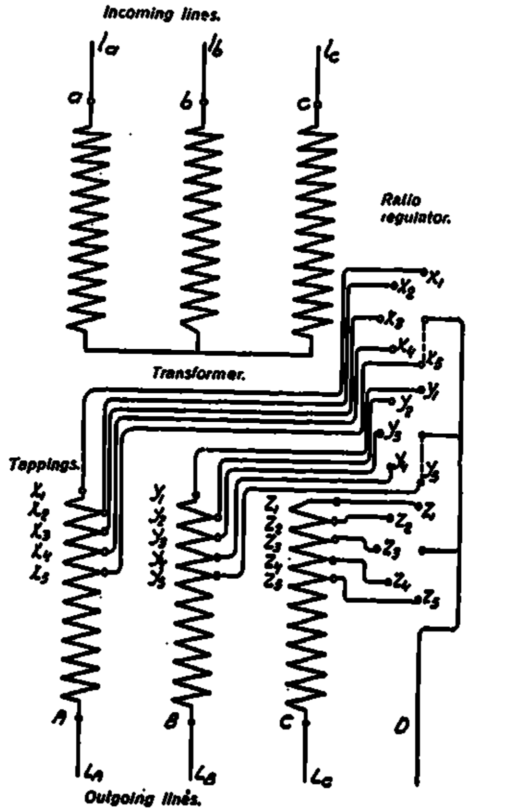


Fig. 3. Diagram of standard power transformer with tappings at the neutral point end of the windings.

nals of the transformer, at the neutral point or in the centre of the windings. Figs. 2 and 3 show the connections between transformer and ratio regulator in the two former cases. The method which is most suitable in any case is in general a constructional question to be settled by the designers of the transformer and ratio regulator. The advantage of the arrangement having tappings close to the terminals is that the number of leading through insulators on the transformer cover is reduced, and this arrangement should accordingly be adopted when there is limited space on the cover. If the tappings are placed at the neutral point, the greatest potential difference between current carrying parts on the ratio regulator is only equal to the magnitude of the range of regulation. The different phases do not accordingly require to be insulated for the working voltage, and it is accordingly only necessary to insulate the complete ratio regulator for the working voltage to earth. For a high tension transformer it is thus only necessary to use a ratio regulator designed for low voltage but mounted on high tension insulators, so that the requisite insulation to earth is obtained. This method of arranging for regulation has often been employed by us already. In view of the present demand for the greatest reliability in working, we do not, however, recommend such an arrangement, but design the ratio regulators just as if they were to be placed at the ends of the winding. There is thus no economic advantage in making use of the arrangement, but somewhat increased reliability is obtained if the ratio regulator which is insulated for the line voltage between the respective phases is placed at the neutral point instead of at the terminals of the winding. The regulating tappings should accordingly be arranged at the neutral point whenever there is sufficient space in the transformer and on the cover, and when great reliability is desired. This, however, is only on the assumption that the ratio regulator is designed as explained above. The arrangement is somewhat more expensive than if the tappings are made at the ends of the winding. The extra tappings should be arranged in the centre of the windings if a relatively large voltage regulation range is required. If the tappings are arranged in the centre of the winding, the magnetic dissymmetry is least. With this arrangement it is easiest to obtain small dissymmetry with small losses and alteration in reactance at different ratios even if a considerable amount of the winding has to be disconnected. This

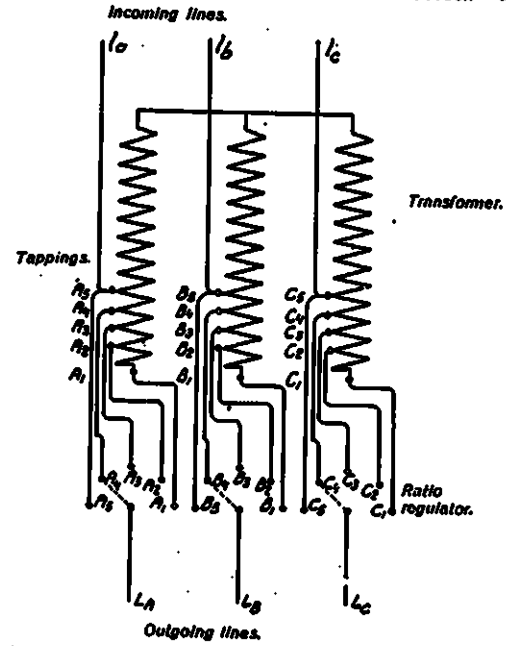


Fig. 4. Diagram of regulating unit with auto-transformer.

arrangement requires still more leading through insulators for the same number of regulating steps, and is accordingly not suitable for a transformer having a small amount of space on the cover. On account of difficulties in bringing

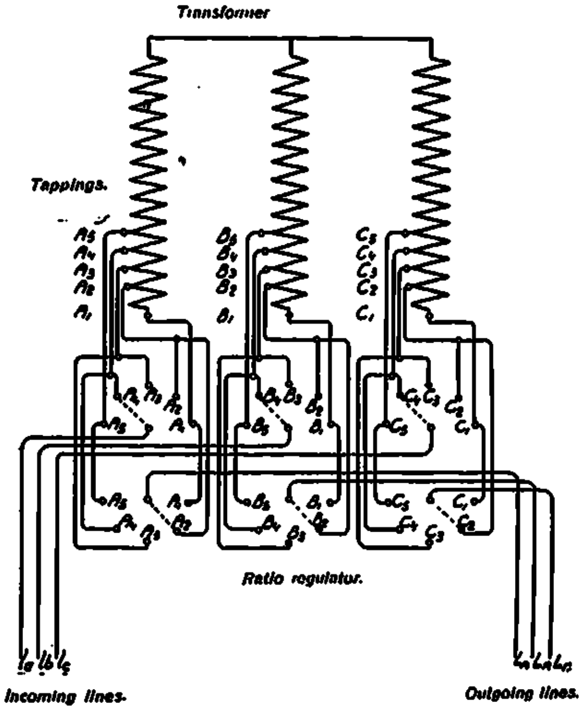


Fig. 5. Diagram of regulating unit with auto-transformer and ratio regulator for ± regulation.

leads from the extra tappings from the centre of the windings through the oil channel between the high and low tension coils, or between the low tension winding and the core, the arrangement cannot be used when regulation is required on the low tension winding of the transformer, provided that this winding is located next to the core. It will accordingly be seen from the above that the location of the extra tappings is a constructional question, and it is not possible to say definitely that any one of the arrangements mentioned is to be particularly preferred, either from the point of view of reliability or from the economic standpoint. The choice of the method to be adopted as most suitable in any case should accordingly be left to the designers of the transformer and the ratio regulator.

For step by step regulation with booster transformers a very large number of different coupling arrangements can come into question, and figs. 4—8 show some examples of these. The simplest case of voltage regulation with a booster transformer is when the voltage at one point on the network is to be kept constant, and when the incoming voltage varies between a constant value and a predetermined lowest value. The scheme shown in fig. 4 holds for this case. The incoming lines l_a, l_b, l_c are connected to the terminals A_5, B_5, C_5 on the transformer, and the outgoing lines L_A L_B and L_C are connected through the ratio regulator to tappings A_5—A_1, B_5—B_1, C_5—C_1, successively. When the incoming voltage is at its highest value, the ratio regulator is placed on terminals A_5, B_5, C_5. As the voltage of the incoming line falls, the ratio regulator is moved to tappings A_4 B_4 C_4, A_3 B_3 C_3 etc., in which manner the outgoing voltage is kept constant. If the booster transformer is arranged as above, the induction in the transformer core falls in proportion to the incoming primary voltage. The transformer cannot then be utilised to an extent corresponding to the material used in its manufacture. It is more suitable in this case to connect the lines which should have constant voltage directly to the tappings A_1 B_1 C_1, on the transformer, and to connect the lines on which the voltage is varying through the ratio regulator successively to terminals A_1 B_1 C_1, A_2 B_2 C_2 etc. The induction in the transformer core is then constant the whole time, and the transformer is fully utilised. In the former case lower iron losses are obtained with the

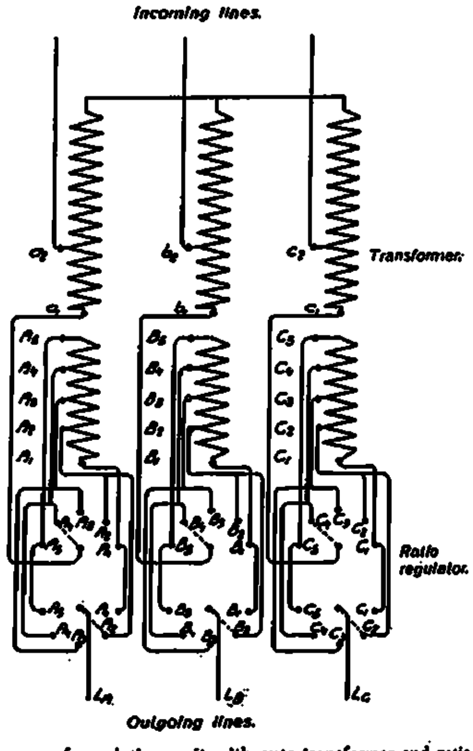


Fig. 6. Diagram of regulating unit with auto-transformer and ratio regulator for ± regulation, with adjustable range of regulation.

lower incoming voltage, but this is not of great importance as the efficiency of the booster transformer as based on the outgoing power is so high that a small reduction in the losses can be practically neglected. In the scheme

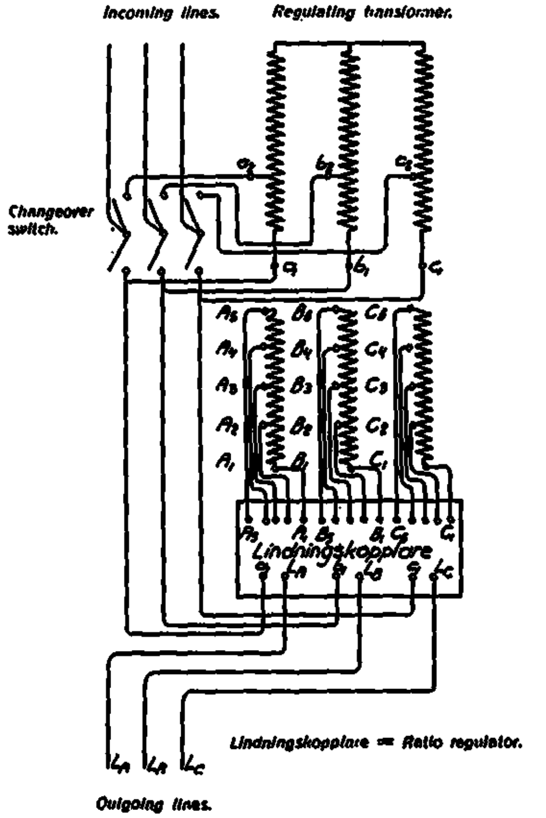


Fig. 7. Diagram of regulating unit with auto-transformer, ratio regulator and 2-way switch.

sketched in fig. 4, it is therefore more suitable that the incoming voltage is constant, and the outgoing voltage raised to compensate the voltage drop in the line. The arrangement is accordingly suitable for voltage regulation on outgoing lines connected to a busbar system with constant voltage.

The scheme shown in fig. 4 allows for the raising of the outgoing voltage in 4 steps with constant incoming voltage. By connecting the incoming lines to tappings A_3 B_3 C_3 instead of to A_5 B_5 C_5, a voltage regulation on the outgoing lines is obtained similarly in 4 steps between the highest and lowest values which lie equally above and below the value of the incoming voltage. In this way a + and − regulation is obtained with an equally large positive and negative range. If the incoming lines are connected to A_4 B_4 C_4 or A_2 B_2 C_2, a ± regulation is obtained that gives a different range for positive and negative regulation.

If the transformers are constructed in the same manner as shown in fig. 4, but with the ratio regulator having 6 sections instead of 3, we obtain a ± regulation with double the number of regulating steps. Fig. 5 shows the diagram of connections in this case. The incoming lines are connected successively to tappings A_1 B_1 C_1 up to A_5 B_5 C_5 by means of 3 of the regulator sections, and the outgoing lines are connected successively from tappings A_5 B_5 C_5 to A_1 B_1 C_1 by means of the remaining 3 regulator sections. When the incoming and outgoing lines are connected to the same tappings A_3 B_3 C_3 on the transformer, the voltage is the same for incoming and outgoing lines. If the incoming lines are connected to A_2 B_2 C_2 etc. or A_1 B_1 C_1 at the same time as the outgoing lines are connected to A_3 B_3 C_3, A_4 B_4 C_4, or A_5 B_5 C_5, we obtain a reduction in voltage, and if the incoming lines are connected to tappings A_3 B_3 C_3, A_4 B_4 C_4, or A_5 B_5 C_5 at the same time as the outgoing lines are connected to A_2 B_2 C_2 or A_1 B_1 C_1, we obtain a rise in voltage. In this manner we obtain with only 5 regulating tappings on the transformer, 9 different voltage steps. In this way the number of extra terminals and leading through insulators on the transformer and ratio regulator is considerably reduced, so that the reliability and

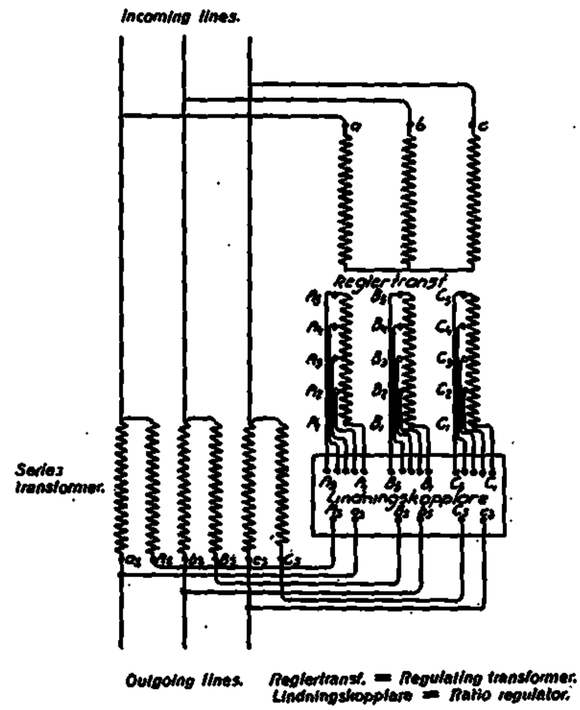


Fig. 8. Diagram of regulating unit with series transformer, regulating transformer and ratio regulator.

the possibility of obtaining a large number of regulating steps, even on small transformers, is greatly increased.

When transformers are furnished in accordance with fig. 5, if the incoming voltage is constant and $= E_1$, and the voltage of the regu-

lating winding is e, we obtain a voltage regulation between $E + e$ and $E - e$ on the outgoing lines. Further, if the transformer is furnished as shown in the scheme in fig. 6, we obtain a displacement of the range of voltage regulation, so that either a purely + regulation or a purely — regulation is obtained, or so that + and — regulation ranges are of unequal magnitude. The number of regulating steps is in every case 8 (9 voltages), although the number of regulating tappings is only 6 per phase. If the incoming voltage remains constant and $= E$, the regulating windings a_1 a_2, b_1 b_2, c_1 c_2, give an additional voltage e_1, and the regulating windings A_1—A_5 B_1—B_5, C_1—C_5 give the additional voltage e_2, and we obtain a voltage regulation on the outgoing line between $E + e_1 + e_2$ and $E + e_1 - e_2$. If e_1 is of equal magnitude to e_2 we obtain pure + regulation between the voltages $E+2e_2$ and E, and if e_1 is equal to $- e_2$ we obtain pure — regulation between the voltages $E - 2e_2$ and E. Lastly, if e_1 is numerically less than e_2 we obtain + and — regulation with + and — ranges of regulation which differ in magnitude.

The possibilities of very extended regulation which are obtained by using the arrangement in accordance with the diagram fig. 6, can be further increased if the method is completed by the addition of a two-way changeover coupling arrangement, which is shown in fig. 7. Here terminals a_1 b_1 c_1 and a_2 b_2 c_2 are connected to the two-way changeover switch, the blades of which are connected to the incoming lines. The terminals a_1 b_1 c_1 as before are connected to the ratio regulator. If the incoming lines are connected to the tappings a_2 b_2 c_2, we obtain the same scheme as shown in fig. 6, and the range of regulation which is obtained is, as before, $E + e_1 + e_2$ to $E + e_1 - e_2$, where E is constant. If the incoming lines are connected to terminals a_1 b_1 c_1, the scheme of connections becomes the same as for fig. 5. If we neglect the fact that with a constant value of E the added voltages e_1 and e_2 with this system of connection are decreased in proportion to the ratio of E to $E + e_1$ with this connection we obtain a regulation from $E + e_2$ to $E - e_2$. The regulating range for the outgoing lines is thus equally large in both cases and is equal to $2e_2$, but in the former case the added voltage e_1 is displaced with relation to the incoming voltage E. The total range of regulation which is obtained in this manner is thus from $E-e_2$ to $E + e_1 + e_2$, and within this range only $2e_2$ can be changed on load with the ratio regulator. The changing over of the two-way switch can be effected when no current is passing, or even under load, if the switch is provided with

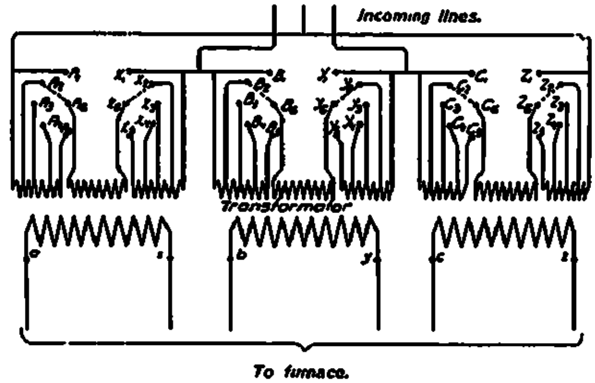


Fig. 9. Diagram showing furnace transformer with ratio regulator, giving large voltage regulation.

suitable intermediate resistance. This regulating arrangement can accordingly be used when different regulating ranges are required during different parts of the day or during different parts of the year. In each range of regulation changes are made by means of the ratio regulator, while the transition from one range to another is made by the changeover switch.

It has been mentioned in a foregoing article that our ratio regulators are not designed for higher working currents than 200 and 350 amperes. By arranging the regulation in accordance with the scheme shown in fig. 8 it is possible to make use of ratio regulators of standard design, even in cases where the line current is considerably higher than the above maximum figures. In this case the regulating arrangement consists of a series transformer (in the figure shown auto-connected), one winding being connected in series with the lines, and the other winding supplied through a ratio regulator from a standard regulating transformer. One winding of this last transformer (the magnetising winding) is supplied from the incoming lines. The other winding is designed as a standard regulating winding with, for example, 5 tappings, and is connected up to a ratio regulator for ± regulation. By a suitable choice of voltages for the regulating winding and the series transformer, the current passing through the ratio regulator can be reduced to any desired value. Whether a series transformer with auto-connected or electrically separate windings is used depends upon the extent to which the current through the ratio regulator must be reduced. When the ratio between the current in the line and that in the ratio regulator is less than 2, it is in general possible to make use of auto-connection. If the ratio is greater than 2, a series transformer with separate windings must be used.

An arrangement as shown in the scheme in

fig. 8, but with a series transformer with electrically separate windings, can also be used if the voltage of the line is higher than the maximum allowable for the ratio regulator. The regulating winding of the regulating transformer, the ratio regulator and the magnetising winding of the series transformer are then quite separate from the lines in the electrical respect, and can accordingly be designed for the most suitable voltage for the ratio regulator, quite independent of the line voltage. Accordingly, if voltage regulation is required on a 100 kV system, this can be obtained by using separate regulating apparatus without having to design the ratio regulator, the regulating winding and regulating tappings for a higher voltage than, for example, 10 kV. It will be clear that this means a very considerable gain from the point of view of reliability.

In a former article it was mentioned that our ratio regulators were originally supplied for regulating the voltage on furnace transformers. The newest types of ratio regulators also are suitable for this service, and fig. 9 shows a scheme embodying a modern universal ratio regulator used for regulating the voltage of a furnace transformer, and giving a very large range of regulation. Each of the six units of the regulator is connected to its own regulating winding in the respective phases, and by successive disconnection of the parts of this winding we obtain regulation of the secondary voltage in 8 steps when the incoming voltage on the primary side is constant.

RAILWAY ELECTRIFICATION IN SWEDEN.

Asea has obtained very wide experience in electric railways at first hand by the electrification of the Riksgrans Railway, as well as a number of privately owned lines and many tramways throughout Sweden. In addition, the electrification of the Oslo-Drammen section of the Norwegian State Railway, and a large number of railways and tramways in Norway, Denmark and Finland are excellent examples of the quality of the equipment furnished by Asea. The results which have been obtained during the twelve years of operation of the Riksgrans Railway (the section of the Swedish State Railway serving the iron ore district in Lapland and having a length of about 450 kilometres) have far exceeded the requirements of the specification which had to be met, and during the time the line has been in use, the suitability of design and good wearing qualities of the electrical equipment has been well demonstrated. As a direct result of this success Asea was entrusted in 1923 with the electrifica-

Fig. 1. 1,700 h.p. electric locomotive with passenger train.

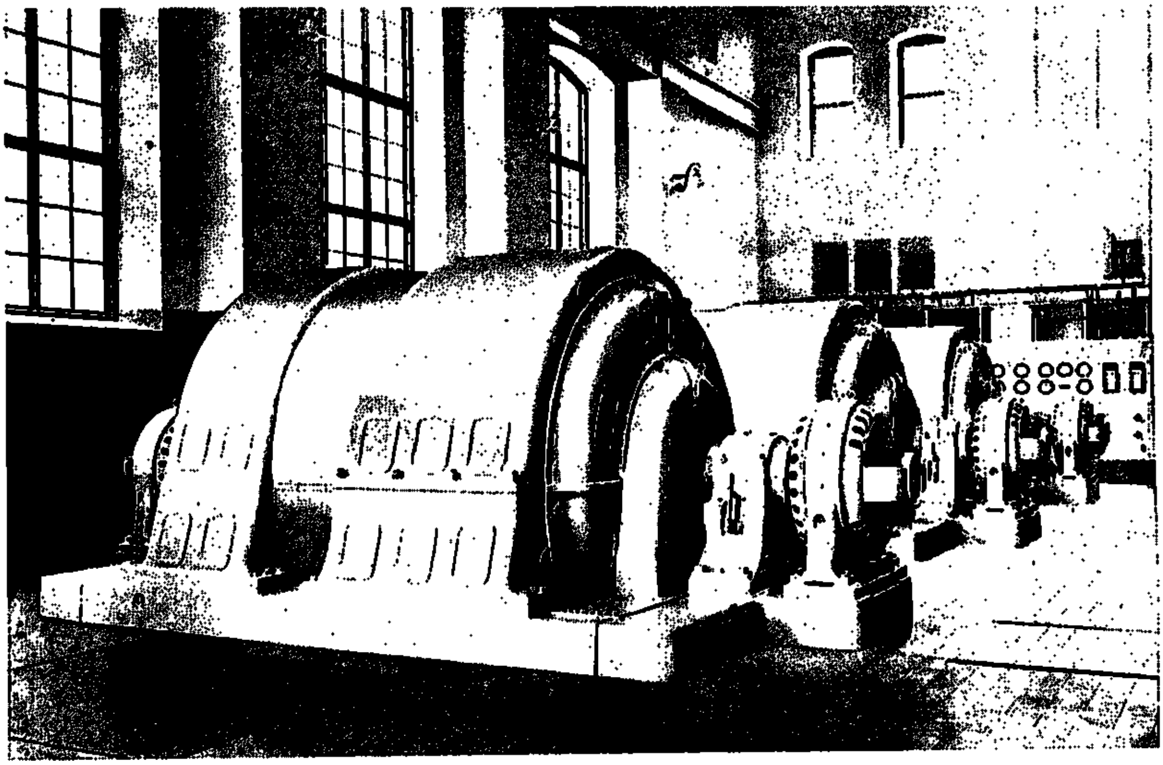


Fig. 2. Interior of the Sodertelje converter station.

tion of the Stockholm—Gothenburg section (458 kilometres) of the Swedish Railway system.

This work is now complete throughout the whole length of the electrified State lines in Sweden, which approximate to about 900 km, and is the greatest stretch of any electrified railway in Europe.

All power required for this line is supplied from power stations which are equipped throughout with Asea generators. This power is distributed by means of apparatus of Asea manufacture, and finally comes to the electric locomotives with their machines, auxiliaries, and apparatus also of Asea construction.

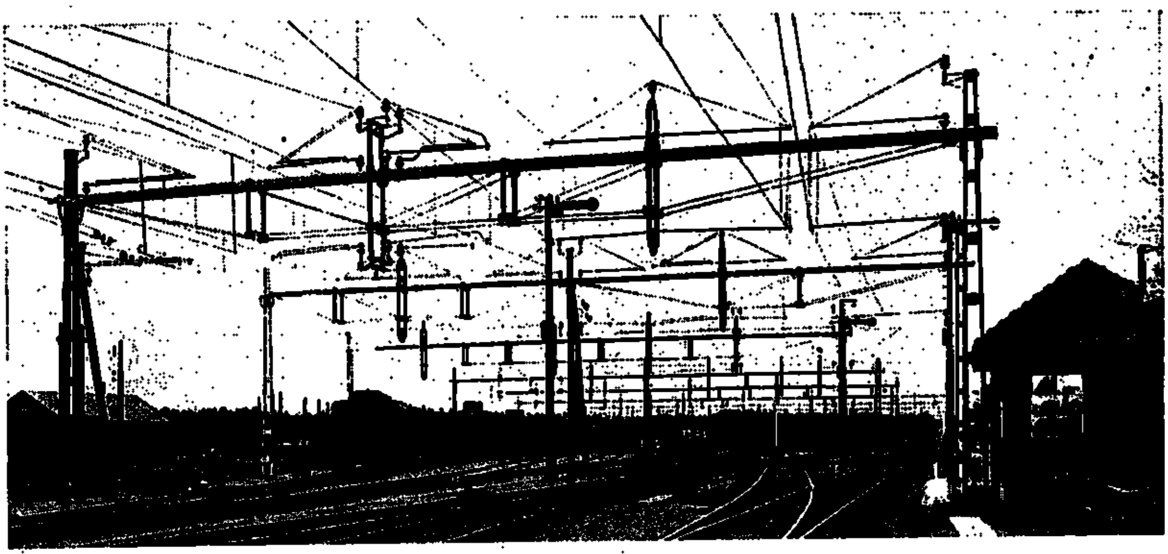
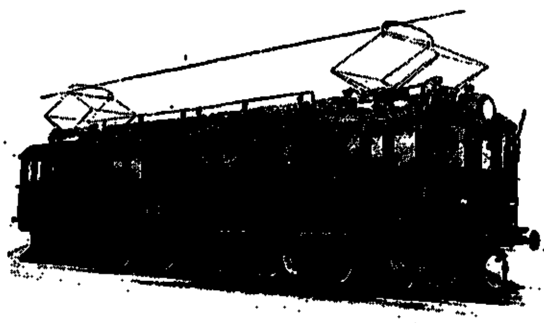
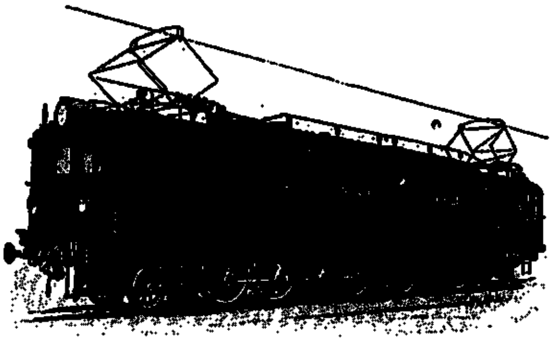
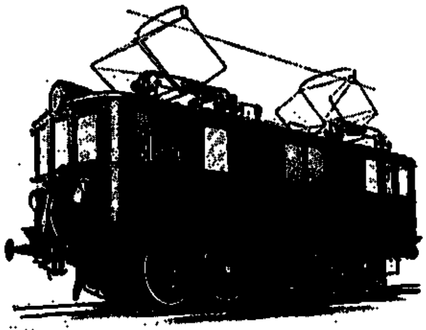


Fig. 3. Contact lines at a station.



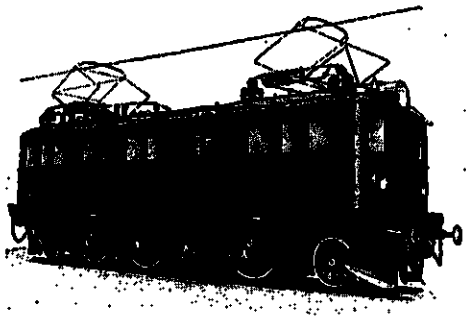




CAN YOU AFFORD TO IGNORE

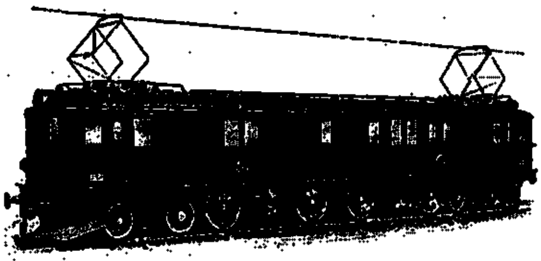
THE ADVANTAGES OF

RAILWAY-ELECTRIFICATION?



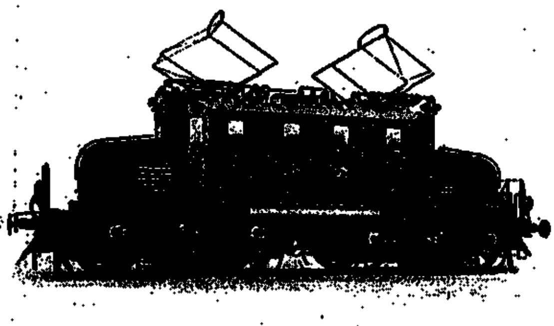
The electrification of a railway gives rise to:

1. Increased traffic capacity due to increased acceleration, train weight and speed.
2. Reduction in engine shed capacity to about one-half — the electric locomotive can be utilised in a far greater degree than the steam locomotive.
3. Power stations and transmission lines are better utilised — power charges to all users are decreased.
4. Decrease in size of shops, staff, repair and upkeep costs.
5. Travelling is quicker, more comfortable and time schedule better maintained.



ASEA has electrified over 1500 km (900 miles) of railways, the contracts including power stations, transmission lines and rolling stock, and the pictures show some locomotives delivered.

Engineers acknowledge unreservedly that Asea are pioneers in the domain of railway electrification and are fully equipped to carry out such work.



ASEA

VESTERÅS — SWEDEN

Vesterås 1926, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

ALLMÄNNA SVENSKA
ELEKTRISKA A.B.
VESTERAS — SWEDEN

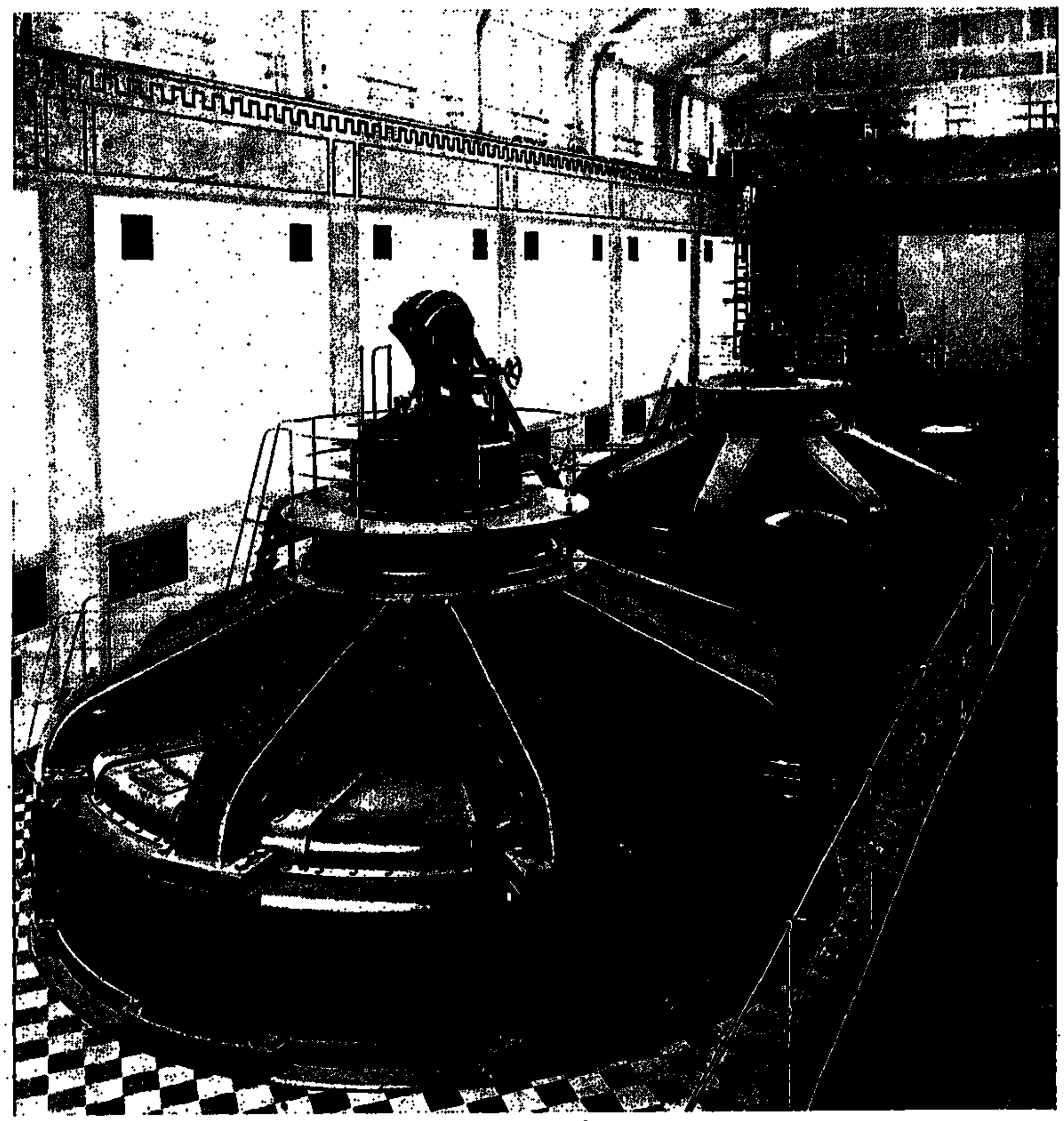
SWEDISH GENERAL
ELECTRIC LTD
5. CHANCERY LANE—LONDON

MONTHLY REVIEW

VOL. III
1926

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesteras, Sweden.

SEPT.-OCT.
Nos. 9-10



Interior of the Swedish State Power Station, Lilla Edet. Three vertical Asea generators of 10,000 kVA at 62.5 r.p.m., 25 cycles, 10,000—11,000 volts.

Sole Agents For British India.

THE LILLA EDET POWER STATION, SWEDEN.

So far the Swedish Government has been responsible for the erection of five main hydro-electric stations and of these the Lilla Edet station is the last to be completed, and occupies the most southerly position. In the case of this power house connects it with the regulating dam in the centre of the river and beyond that a series of dams and sluices continue across to the western bank. By means of a temporary dam construction, the station is further connected

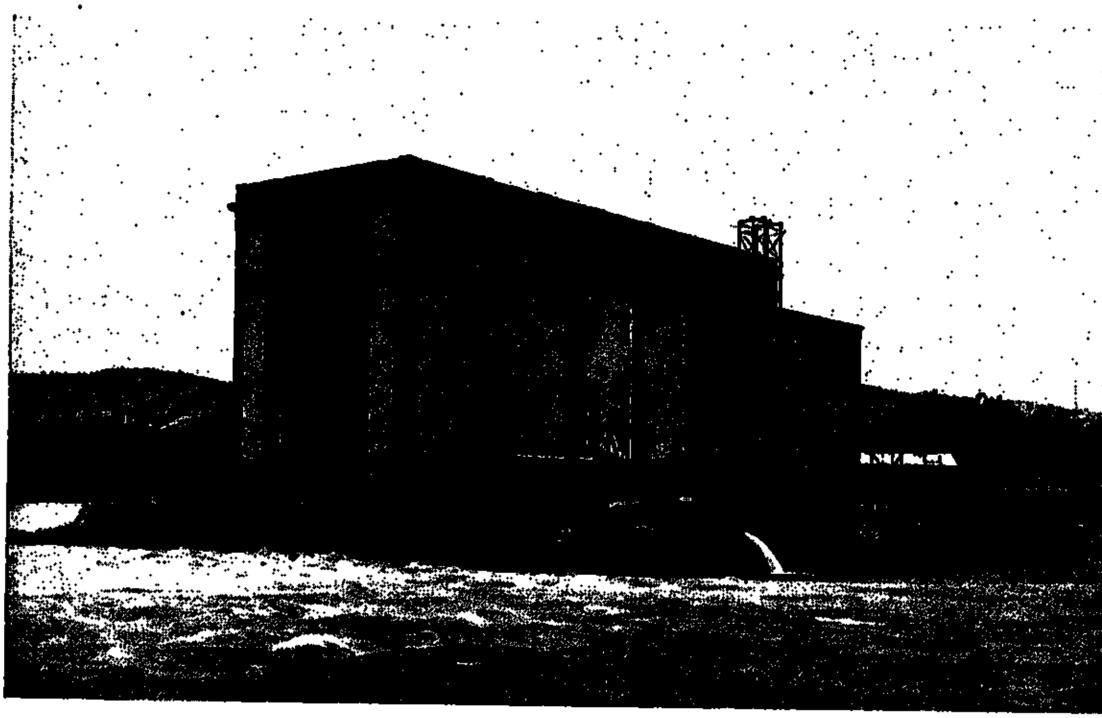


Fig. 1. The power station from the South West.

particular plant a great deal of preliminary work was carried out many years ago, but the actual construction did not commence until 1918 when the Swedish Riksdag decided to proceed with the scheme. The station is located on the Gota Elv (River) at the point where the last of the three main series of falls occurs; that is to say, about 55 km from the mouth of the river at Gothenburg, and 35 km. from Vanersborg, the source. On the site there were previously two industrial undertakings — the Lilla Edet paper mill and the Inlands paper works — which made use to some extent of the water power available in the falls. These plants were purchased by the State and the old paper mill buildings have been pulled down and a power station building of most modern design erected in their place. This building is located on the eastern bank of the river, and the first section which has now been completed represents the end of the station projecting farthest out into the river and houses three units, each of 10,000 h.p. A new dam, starting from the north western corner of the to the eastern bank to which a temporary railway bridge also leaves access across this so far uncompleted part of the power house.

Having regard to the existing demand for electrical power, it was intended when the buildings were put in hand to have the work completed, and the station put into service by 1921. Meanwhile, however, the industrial crisis following the War period caused a very considerable decrease in the power demand. At one time it was even debated whether the constructional work should be abandoned until a more favourable time. Happily, a change in conditions occurred and the work was continued, although somewhat slowly, and the time was further extended due to the occurrence of some unfortunate strikes so that the opening of the station which, in accordance with the altered plans, should have taken place in 1924 was further postponed until the present year, when the first unit was started up on the 7th of January.

The plant is one of the most interesting which has been set to work in recent years. Particularly

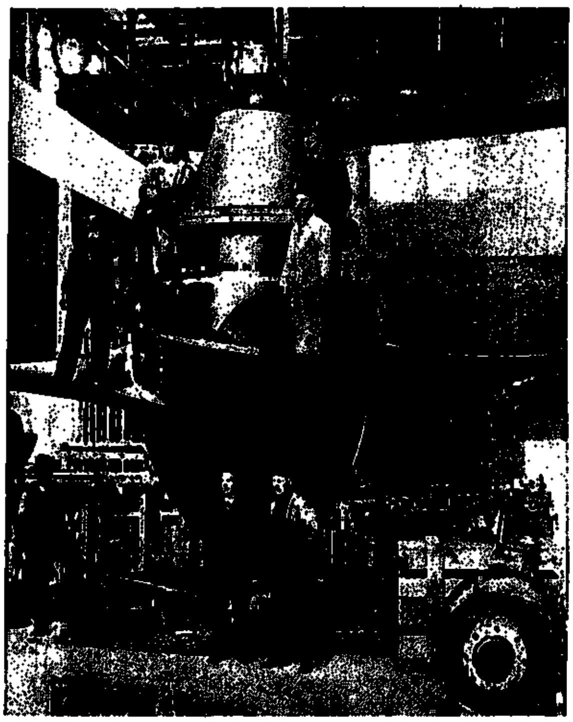


Fig. 2. Runner of Kaplan turbine with movable blades.

from the hydraulic point of view it differs in many characteristics from other large hydro-electric power stations in all parts of the world. Not only are the three turbines of an entirely new type, but as regards dimensions they are the largest in the world. The turbine intake arrangements, and also the headrace and tailrace designs, differ considerably from those which are commonly used, it will be appreciated in particular that the great quantity of water which, at full load, is approximately 150 cubic metres per second for each turbine and the very low head which is only about 6.5 metres, has made it necessary to adopt constructions very unlike those used on previous occasions. By a particularly complete preliminary investigation concluded with careful tests on models, a number of which were shown during the Göthenburg Exhibition in 1923, the Swedish State Power Board were able to make all necessary preparations for the work, and to ensure that the type of machine chosen would be an entirely suitable construction.

Of the three turbines which are all of the so-called propeller type and with single wheel and vertical shafts, one is a Kaplan turbine with movable impellor wheel blades the overall diameter of the impellor being not less than 5.8 metres, while the other two sets are Lawaczeck turbines with rigid impellor wheels of 6 metres diameter. Both types of turbine are noteworthy on account of the high full load efficiency which reaches approximately 88 per cent, and in the case of the Kaplan turbine can be maintained unaltered to a considerable degree with other loads right down to half load due to the moving blades while in the case of the Lawaczeck turbines, although these are considerable cheaper in first cost, the efficiency decreases to a considerable extent even when the load falls slightly below the full value. With the system of working adopted, however, this is of less importance as the units equipped with Lawaczeck turbines are run fully loaded and any additional surplus load is carried by the Kaplan turbine, for which purpose it is particularly suitable. Each turbine has only one guide bearing and the impellor wheel is supported together with the rotor of the direct coupled alternator by an upper supporting bearing placed above the generator. The auxiliary machinery etc., is constructed and installed in the usual way and differs only from that used on other turbine instalations of the same sort in its size and in certain small details. On the other hand the operating machinery for the blade system of the Kaplan turbine, which is arranged inside the boss of the impellor wheel and is provided with necessary connections running through the hollow turbine- and generator shaft, is of a construction which is entirely special for this particular turbine.

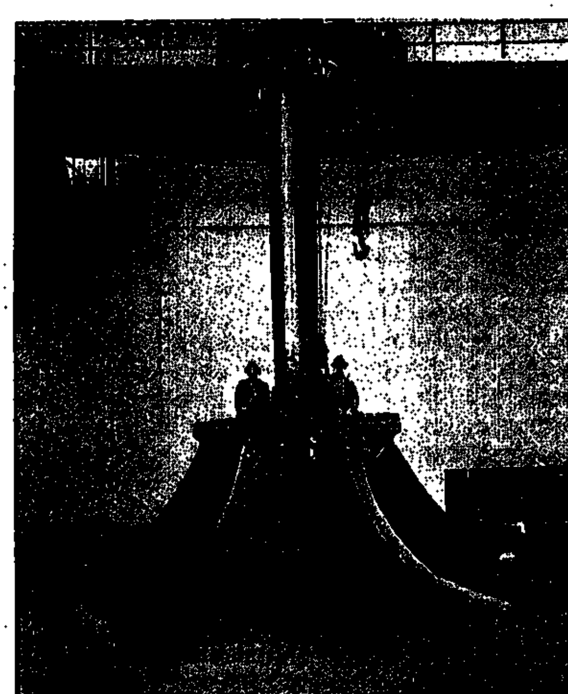


Fig. 3. Runner of Lawaczeck turbine with fixed blades.

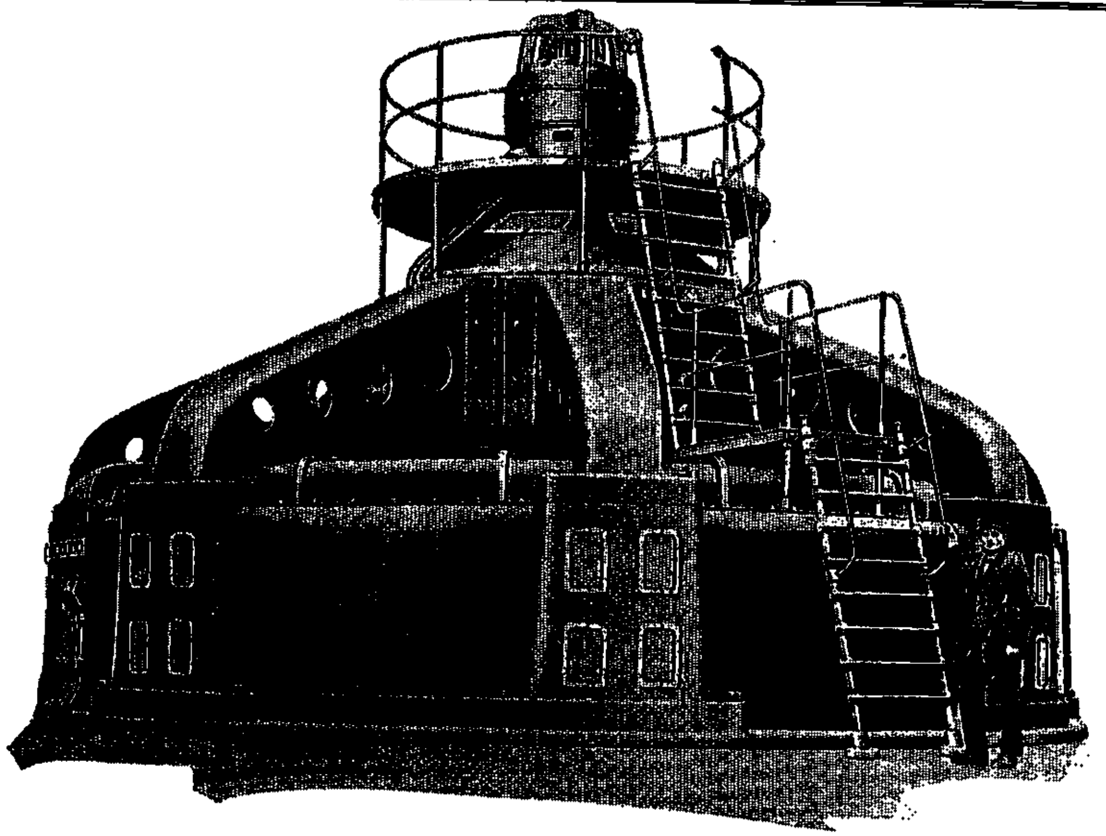


Fig. 4. Generator No. 2 with exciter at the top on platform with handrail, beneath which is seen the supporting bearing housing and armcross which rests upon the stator. The lubricating and cooling pipes can be seen on the left.

The three-phase generators of which two were ordered in the summer of 1922 and the third two years later are all of Asea manufacture and with a few exceptions are all of exactly similar pattern. They are designed for a continuous output of 10,000 kVA at 62.5 r.p.m., 25 periods per second, 10,000—11,000 volts and $\cos \varphi = 0.7$. At the time the order for these generators was placed it had not been finally decided for what periodicity the Lilla Edet station should be built, and it was accordingly specified that the machines should be constructed for 25 periods but so designed that they could be altered to 50 periods with the least possible expense if it should be found desirable. It was required at the same time that they should be able to give the same output at either of these periodicities without alteration in speed, voltage, or power factor, etc. The two Lawaczeck turbines have direct coupled generators each with its own exciter, while the excitation for the generator of the Kaplan turbine is obtained from a separate exciter unit. The excitation voltage is 220. To cover the design, erection, guarantees and testing etc., of the generators the Swedish Waterfalls Board prepared a detailed specification. Like the turbines, the generators were also at the time the largest, which had been built of this pattern in Sweden. Having regard to assembly and coupling up to the turbines, they were made of vertical pattern, furnished with supporting bearing mounted on supporting arms, which also carry the guide bearing, the stator of the exciter and platform for inspection etc., and have underneath another armcross carrying the second guide bearing, the brake and lifting gear etc. They are further totally enclosed and self-ventilated and like all large A.C. generators have rotating field magnets and fixed armature.

The dimensions of the power station building made it necessary that the overall diameter of the machines should not exceed 9.7 metres, while the turbinebuilders required that the inner diameter of the base ring should be at least 7.8 metres. Having regard to this last requirement it was found that the stator diameter could be 9.45 metres so that the distance between the various units is somewhat greater than the minimum allowed. The base ring is grouted to a concrete foundation to which it is fixed by foundation bolts and anchor plates and carries the stator housing which has been made in four parts of cast iron to facilitate transport and erection. The housing is of such dimensions

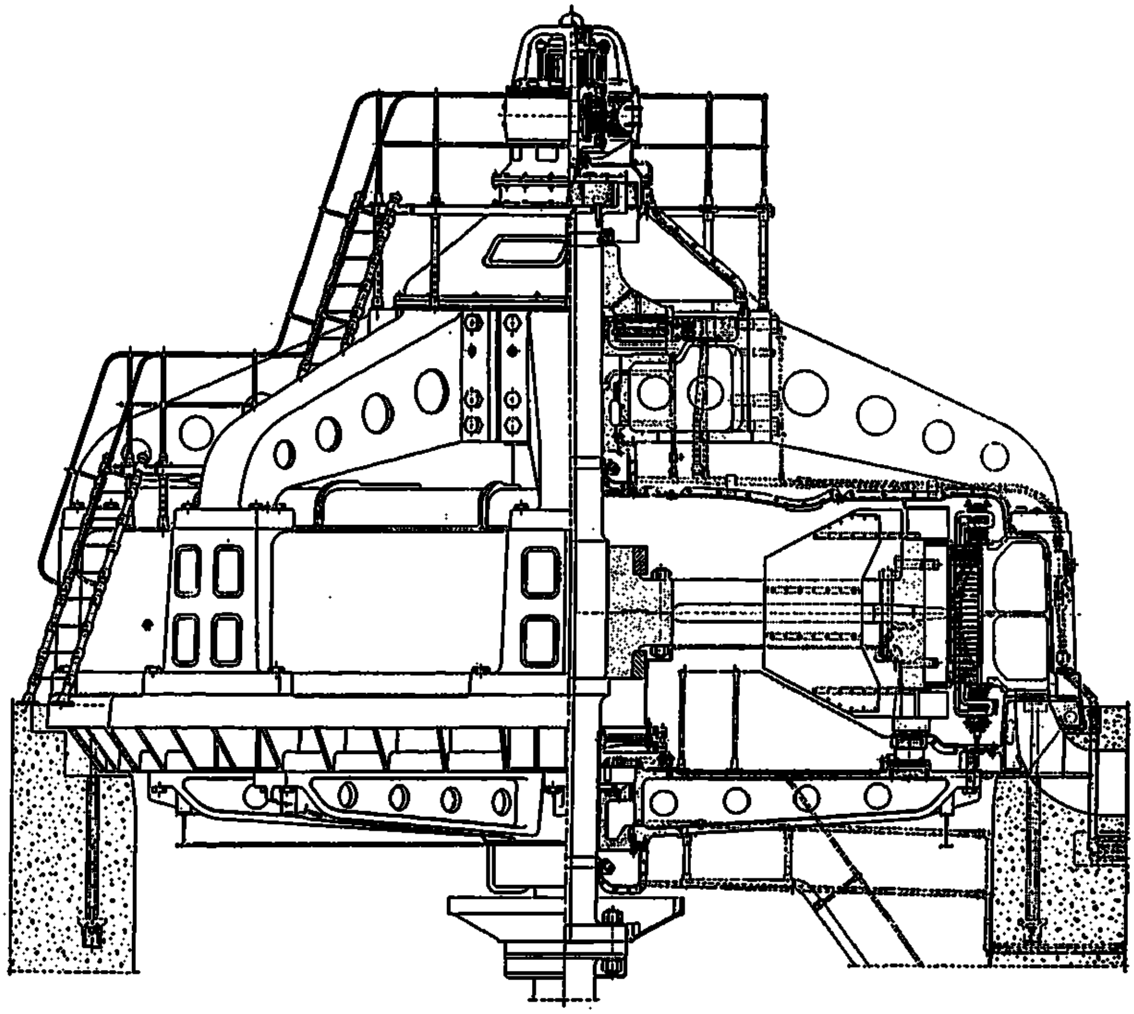


Fig. 5. Elevation of generators Nos. 2 and 3.

and is so designed that it acts as a collecting duct for the warm air escaping from the inner parts of the machine, and on this account the exterior has no openings except at the points where the eight supporting arms are fixed and where four removable covers are used in each position to allow access to the inside of the stator housing for inspection etc. From the interior of this housing the heated air is lead downwards through openings in the inside and in the base ring to a duct in the machine room. The inner cylindrical periphery of the stator housing is furnished in the usual manner with clamping rings for the armature laminations which are securely keyed in position and held together by strong press flanges. On account of the low periodicity the depth of the armature is considerable and ventilation is provided for by a large number of ventilating ducts of the same width although with a somewhat different spacing in the axial direction so that the stacks of laminations are of varying thicknesses according to the expected variation in ventilation and the most even division as possible of heating is obtained. Each generator contains approximately 37 tons of best Swedish dynamo plate.

Bearing in mind the possible alteration to 50 periods the stator winding differs somewhat from the usual Swedish practice. It is designed as a coil winding with two coil sides in each slot. At 25 periods the winding has three slots per pole and phase, and the coil sides are completely finished as regards conductor and slot insulation and bent into shape before being placed in the open armature slots where they are afterwards made fast by means of fiber wedges. After being placed in position they are connected up, the end connections being then finally insulated and clamped in winding supports which are composed of two circles of bolts carried in the press flanges, one circle

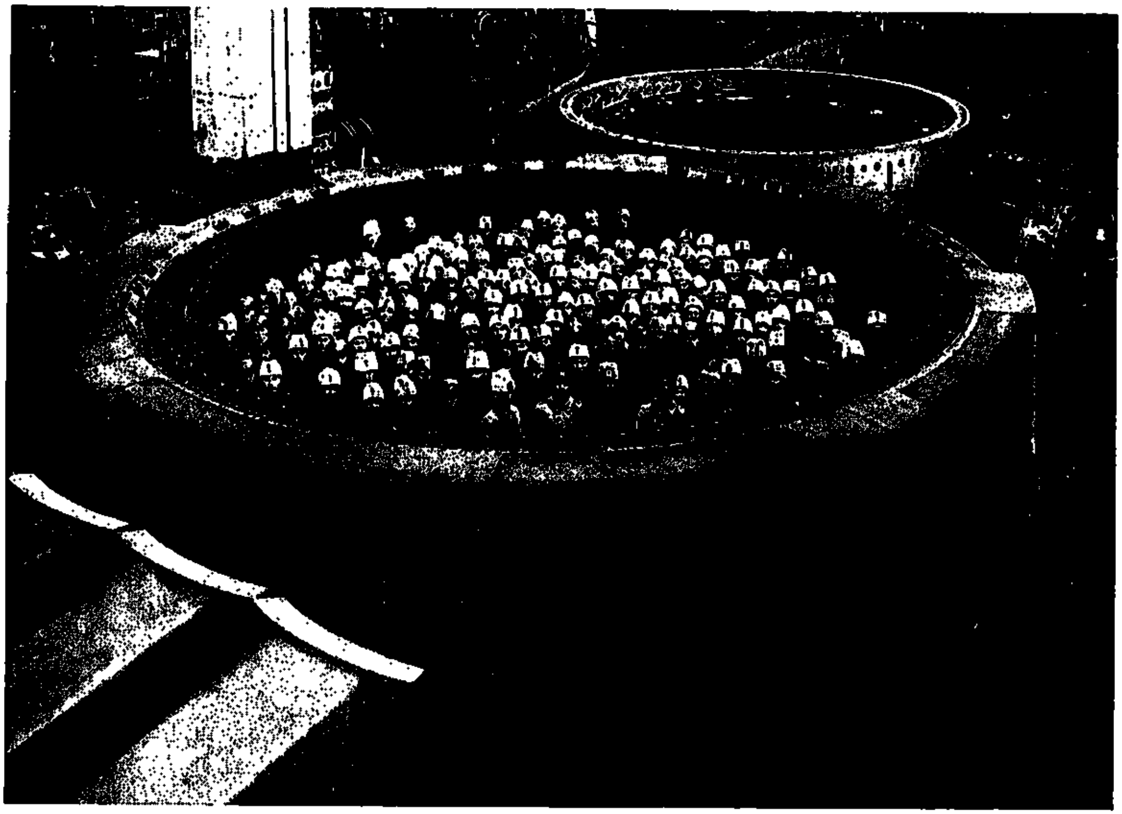


Fig. 6. A company of Swedish troops in a Lilla Edet stator.

inside and the other outside the winding and arranged in pairs which are connected together by radial clamping plates. This winding is much favoured and is considerably used in America and certainly possesses some advantages, but there are also various drawbacks which are not met with in the coil windings which have the winding divided in different planes and are used to a greater extent in Europe. It has been used here because the necessary alteration of the stator winding when changing the periodicity is simpler to carry out. When making such a change there is no need to withdraw the winding from the slots and all that has to be done is to shorten the winding step by altering the end connections and to renew the insulation on the end windings, and this can quite easily be effected at the power station. As the radial width of the end windings is decreased about one half with an alteration to 50 periods on account of the shortened coil step the winding clamps are furnished with new specially finished packing pieces after the winding has been reconnected, and in this way the clamping bolts suit equally well and provide the same firm support which they

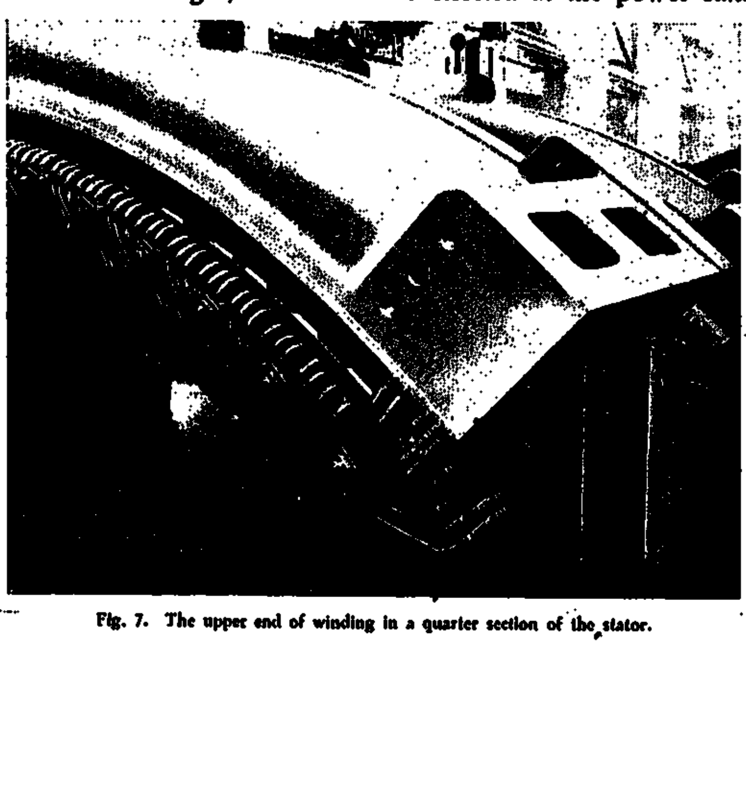


Fig. 7. The upper end of winding in a quarter section of the stator.

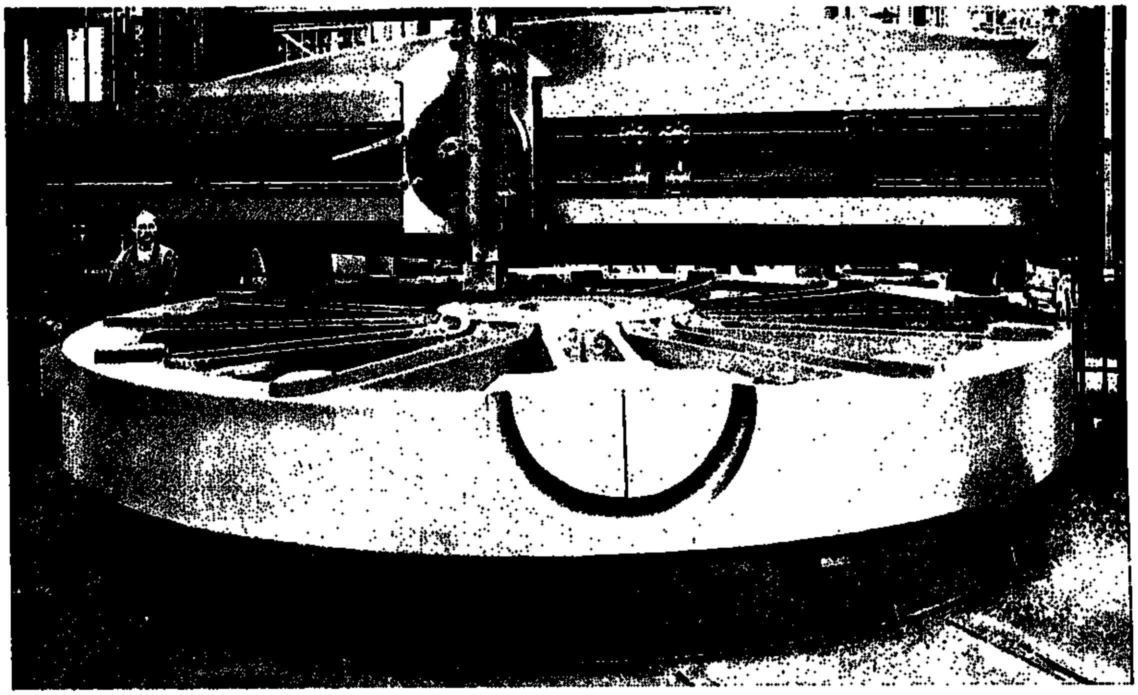


Fig. 8. A rotor half undergoing machining on large turning mill in the Emaus works.

gave with the original arrangement. The insulation of the winding is particularly heavy and carefully applied on account of the high machine voltage, and the pressure tests specified, which are in accordance with the Swedish regulations. Next to the copper conductor sections an impregnated double cotton covering is used. The sections of a conductor are thereafter insulated throughout with micanite insulation applied under pressure when hot, and afterwards

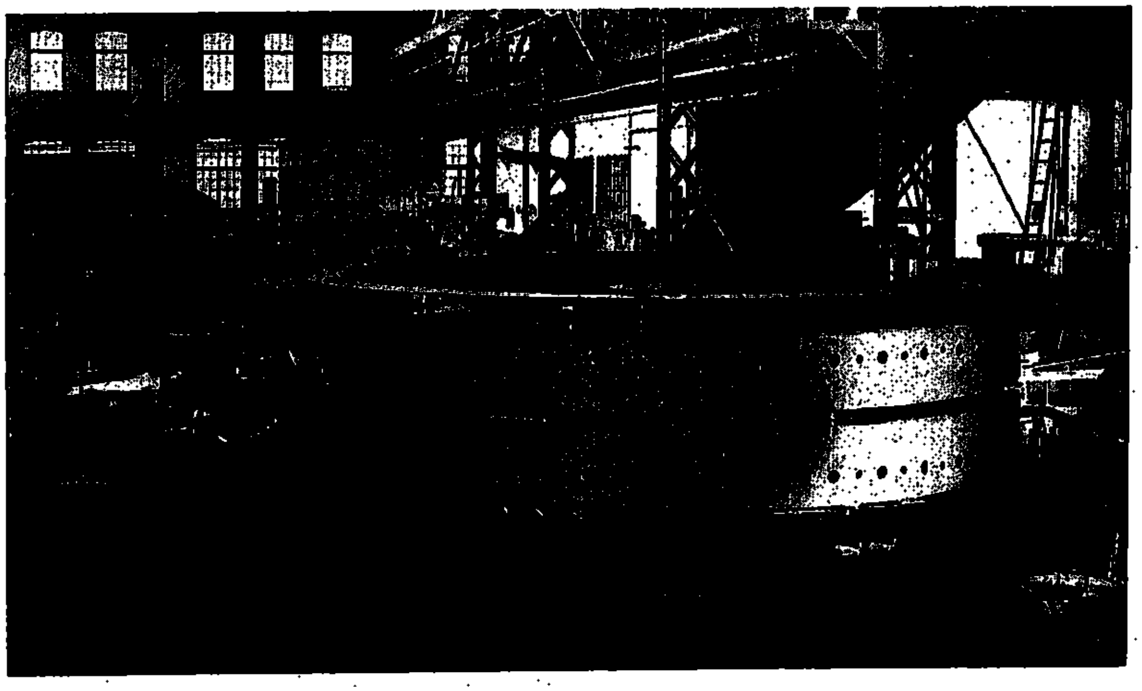


Fig. 9. A rotor without poles showing the side ring at the bottom, the upper and lower fan wheels, and the caps shrunk on holding the two rotor halves together.

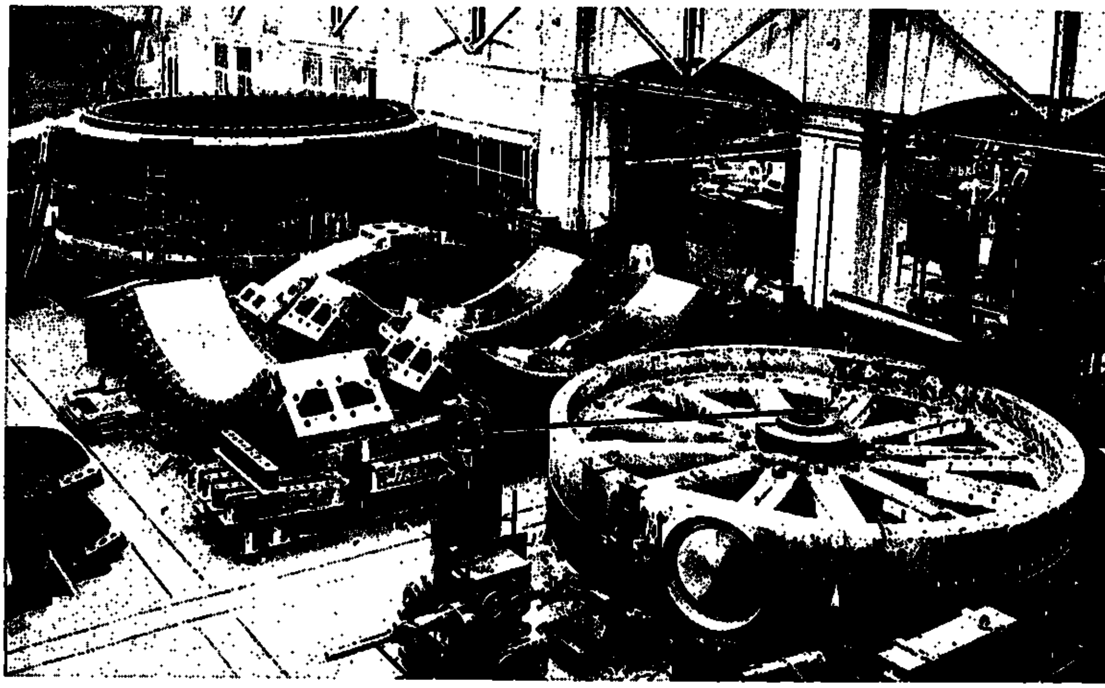


Fig. 10. View in the shops showing parts of the Lilla Edet generators.

slot insulation is placed round all conductor sections forming a coil side, and for this mica covered paper is used wound on in a special machine. The insulation is finished to a size which allows the necessary small clearance to enable the coil side to slip easily into the slot, and has a thickness between copper and iron of 6.5 mm and is composed chiefly of mica as will be seen from the above. The slot insulation is extended as usual along the free ends of the coil sides beyond the core plates as long as the coil is straight and is united where the coils are bent with the insulation of impregnated fabric and tape used on these parts and which are strengthened by special arrangements for separating the phases and providing additional insulation to the winding clamps. These last have their own insulation consisting of micanite tubes on the outside of all the clamping bolts and intermediate and under packing pieces of micanite under the clamps themselves and between the various parts of the winding secured. Although the free parts of the windings are relatively short and the effective length great in comparison with the total length, the weight of copper employed in the armature winding of the machine is not less than 7.5 tons.

The winding has six terminals, that is to say, one for each end of each phase and the winding can be connected outside the machine. The neutral point is earthed through a resistance.

Both above and below the end windings of the stator are protected by cast iron covers furnished with inspection doors of steel plate. The lower covers extend radially inwards as far as the inner edge of the field magnet ring, but the upper covers are extended right as far as the shaft centre, sector shaped cover plates being used so as to completely enclose the generator under the upper supporting armcross.

The rotor is made with boss, arms and yoke ring of cast iron, having extra high tensile strength and the pole cores and pole shoes are of cast steel secured to the yoke ring by bolts. On account of transport difficulties the rotor had to be subdivided and the arms and boss are accordingly split on a plane at right angles to the shaft into two rotor halves which are held together by axial bolts in both the ring and the boss. These rotor halves were also too large for transport purposes and it was necessary to divide these again on a diameter. All these four rotor parts are secured together at the boss by shrink rings and at the periphery of the yoke ring by caps of special steel. The pole cores which are of cast steel have in the centre an air duct which corresponds with a radial duct arranged in the joint between the two rotor parts and continues through the pole shoes to the air gap, giving a very effective cooling to the inner parts of the stator. The end parts of the pole shoes are cast in one piece, with the pole cores but the outer parts, which are turned towards the air gap, are laminated

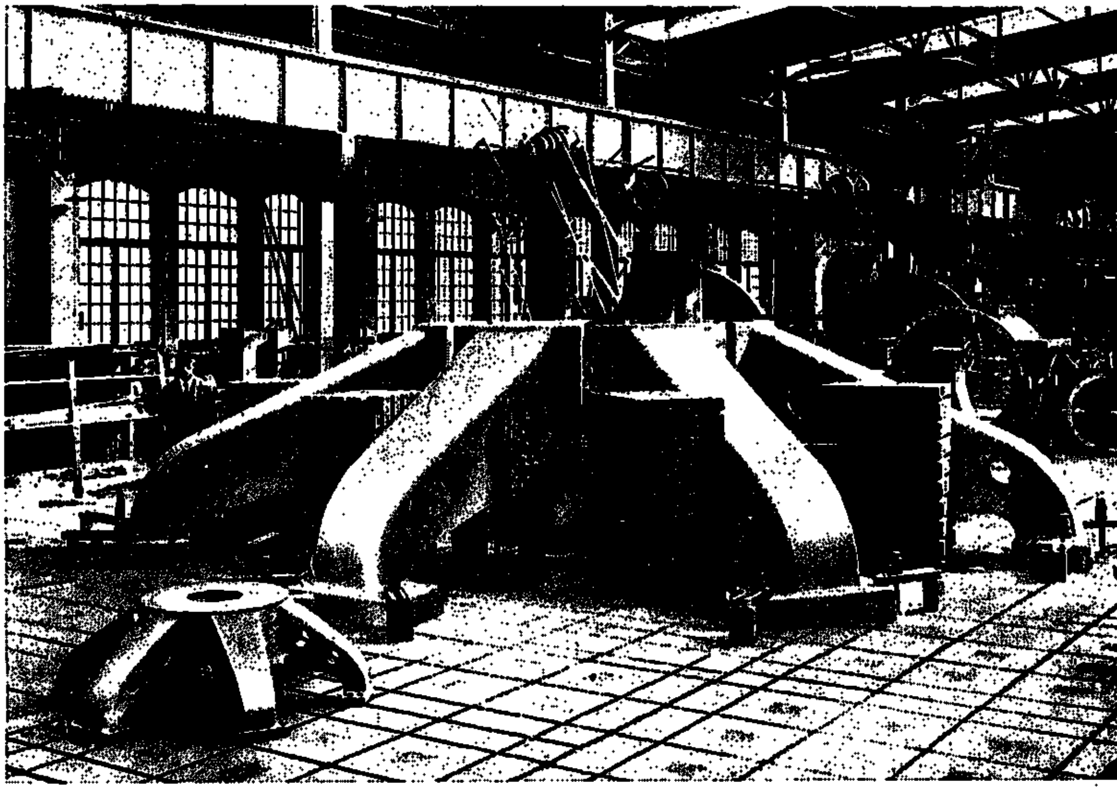


Fig. 11. In the foreground an 8.5 ton armcross, in the rear a Lilla Edet generator armcross for a load of 600 tons.

and so shaped and located that the generator voltage curve is, as nearly as possible, of pure sine form. As in the case of the stator certain necessary work was carried out to simplify the projected alteration to 50 periods, and on this account the rotor yoke rings have been drilled suitably to accomodate double the number of poles as required for 50 periods.

For the turbine speed regulation a flywheel effect corresponding to 230 kgm per h.p. at normal speed was required corresponding to not less than 4,250,000 kgm^2 in the rotor. Due to the very large diameter it was only necessary to use one small side ring placed beneath the rotor yoke ring and this is not of any abnormal section in comparison with that requisite having regard to the tensile stress and the magnetic qualities. The whole of the flywheel effect could without great difficulty have been secured in the main field ring, but at the time the generator was designed the arrangement chosen was considered to be most suitable. The side ring, for instance, is made to act as a track for the brake in conjunction with the hydraulicly operated braking arrangement carried on the under-arm cross and which is used, not only for stopping the machine when necessary, but also for lifting the rotor by a small amount when carrying out inspection or repairs on the segmental bearing. The brake arrangement is so powerful that the generator can be brought to rest from full speed in less than one minute.

The field winding is of copper strip wound on edge and insulated in the usual manner with shelac paper between turns and presspan collars and cylinders to the iron core. As the number of turns per pole is relatively small, and the necessary conductor cross sectional area large on account of the high field current the winding is arranged with two parallel connected strips, one being thinner and broader than the other so that the projecting edge acts in the same way as cooling flanges on the coil. The windings are connected to the slip rings in the usual manner and the slip rings themselves are placed below the rotor at a convenient height above the lower armcross and guide bearing and easily accessible from a platform which is placed there. The weight of the rotor winding is approximately 9.5 tons.

The rotor is fitted with fan blades which are so designed as to be able to circulate the necessary amount of air for cooling the generator and overcoming the resistance in the intake and

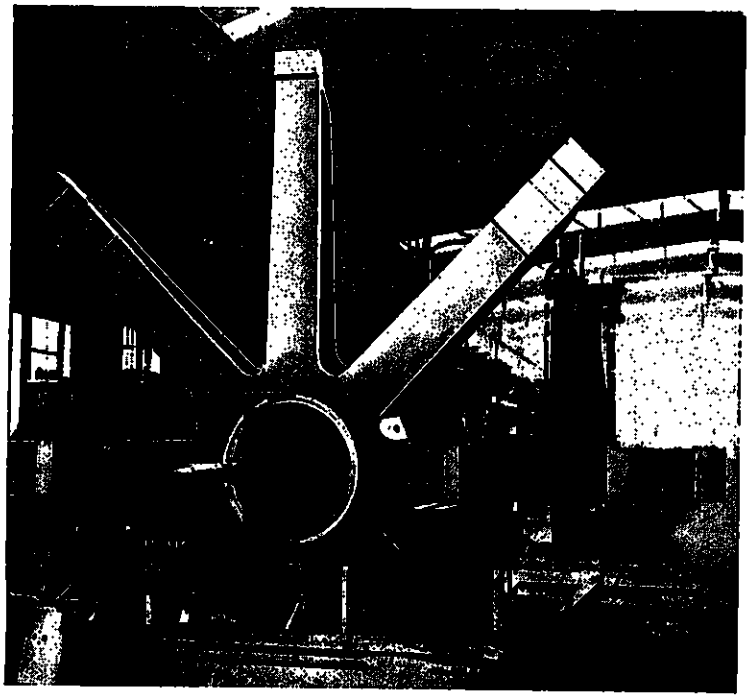


Fig. 12. Lower armcross.

outlet air ducts in the station. Due to the low speed it has been necessary to take special precautions to secure an adequate quantity of cooling air. The rotor accordingly has fan wheels of the usual type arranged above and below it, but in addition large fan blades are placed on the arms of the magnet wheel which serve to give the current of air a tangential direction before they actually reach the fan wheels, the action of which is thus assisted. The large fans also drive part of the air through the radial duct arranged in the centre of the rotor. The quantity of cooling air required for adequately ventilating the machine allowing an increase in the air temperature of 20° C, is considerable and reaches approximately 20 m^3/sec.

The shaft and guide bearing only differ in dimensions from those of other similar vertical generators. The former for all three generators are cored out throughout their whole length in order to provide a check on the quality of the steel. In the case of the Kaplan turbine unit the hollow in the shaft serves to contain the regulating arrangement for operating the blades of the turbine runner. At the lower end the shaft has a solid flange for connecting to a corresponding flange on the turbine shaft and at the upper end a locking ring is arranged for securing the rotating part of the supporting bearing. On the two generators drived by Lawaczeck turbines the upper ends of the shafts are fitted with a pinion for the planetary gear for driving the exciters of these units. The gear ratio is approximately 1 : 6 so that the exciters run at 400 r.p.m. although the generators have a speed of only 62.5 r.p.m. The Kaplan turbine driven generator receives excitation from a separate exciter unit and accordingly requires no exciter of its own. In this case at the upper end of the shaft is placed a special regulator which controls the position of the impellor blades in relation to the gate opening. The shaft weighs approximately 14 tons.

The guide bearings are ordinary babitt lined sleeve bearings fixed in the two armcrosses so that they can be easily slid downwards along the shaft and dismantled if this should be necessary for any reason. The supporting bearings in all units are of the Asea segmental bearing type with which many years experience has been obtained. This bearing consists of a supporting plate fixed on the shaft which rests upon 16 segmental babitted bearing surfaces which, in their turn, are bedded upon a total of 496 spiral springs which transmit the load to the bearing housing. The segments are entirely immersed in oil in an oil well arranged in the centre of the upper armcross, the lower part of which carries the upper guide bearing. To this armcross centre the eight supporting arms are secured with heavy bolts the other ends resting upon the stator housing. Through the supporting bearing a load which under certain conditions can reach 550 tons is transmitted from the rotating parts to the armcross. Of this weight about 320 tons are due to the unbalanced water pressure, the remainder being the weight of the rotating parts of the generator and the turbine. In addition to this load the armcross has also to support the bearing, exciter, gearing etc. so that under the most exacting conditions nearly 600 tons have to be supported.

All the bearings are lubricated and cooled by oil circulation. The oil circulation is obtained from a motor driven centrifugal pump erected in the basement which raises the oil to the well of the supporting bearing, to the guide bearings, and to the gear on the generators which are furnished with direct coupled exciters. From the bearings the oil drains to a common sump where it is cooled and filtered before being returned once more to the bearings.

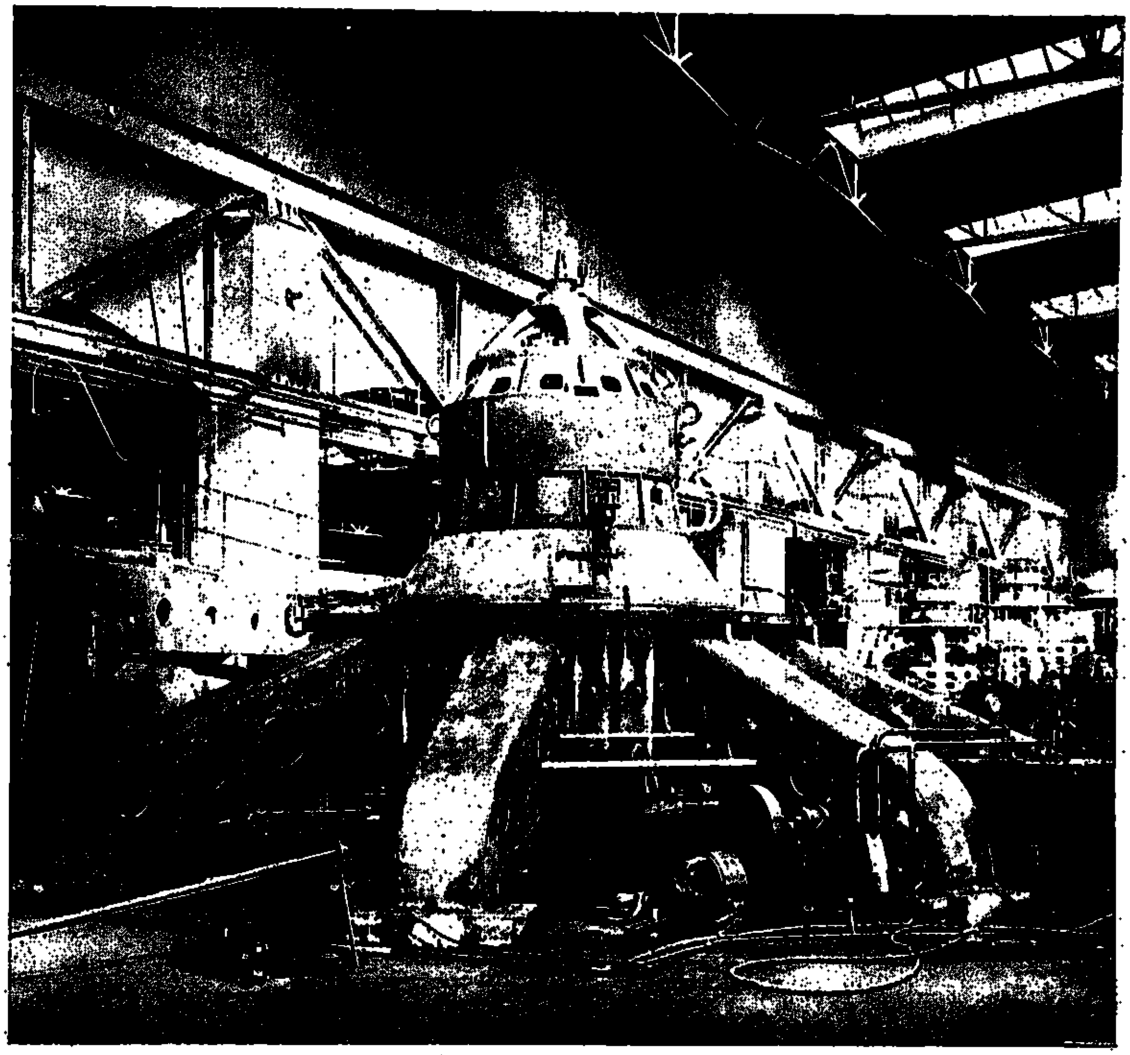


Fig. 13. The rotor is erected in the pit below the armcross for run-away test.

The supporting bearing has in addition an arrangement for water cooling by means of a coiled pipe in the oil well. This provides a standby arrangement if the oil circulation should be arrested due to a breakdown in the pumping unit. In such a case the pump of one of the remaining units would be connected up, so that the guide bearings of two generators could obtain oil from one pump, while the supporting bearings of both generators would be cooled by means of water circulation.

All bearings are furnished with two distant reading thermometers, one of which has an indicating dial visible from the controlling arrangement for the oil circulation, the other being arranged for reading in the switch control room. The bearing temperatures and the temperatures of the cooled oil can be read from the controlling position for the oil circulation. At this point a hand-pump is also arranged, which is used for braking and for lifting the rotor. This pump is so designed that when it is set for braking it is quite impossible to reach such a high oil pressure that seizing can occur between the ring and the brake shoes.

The size of the machine can be appreciated from the various photographs. As mentioned above the outer diameter of the stator housing is 9.45 metres at the floor level, the highest point of the machine being 6.3 metres above and the lowest point, the shaft flange, 2.35 metres below the floor. The complete machine weighs about 350 tons, of which the rotating parts account for approximately 150 tons, and the stator 100 tons, the remainder representing the armcrosses, bearings, base ring and other accessories.

In the present article we have not entered into the question of guarantees or tests results and it is hoped to deal with these questions at a later date.

STABILITY OF OPERATION FOR D.C. MACHINES.

When a D.C. motor (or a generator) carries a load, steady conditions are arrived at when the torque developed is equal to the counter-

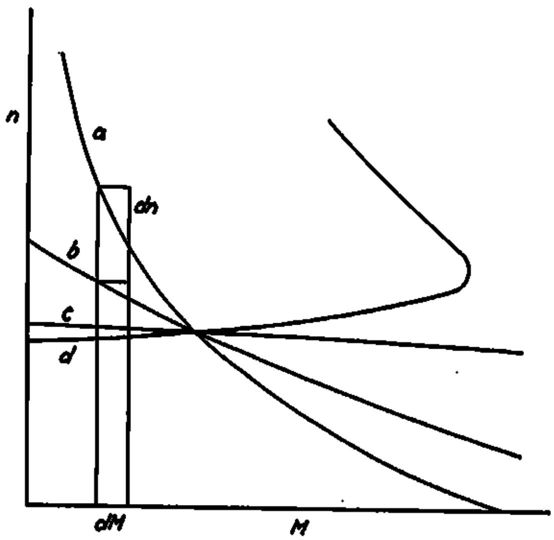


Fig. 1. $n = f(M)$ for various motors (constant voltage).

a. Series motor. b. Shunt motor with compounding. c. Plain shunt motor. d. Shunt motor with opposing series winding.

torque caused by the load. Whether this condition is stable or not depends on the characteristics of the machine and the load. An investigation of the requirements for stability (or for the »static» stability) is the object of the present article.

If the torque supplied is not of equal magnitude to the torque due to the load, the difference is absorbed by an acceleration or retardation of the moving masses (or in self induction or capacity of the circuit). The conditions of stability under these circumstances (the »dynamic» stability) will not be dealt with.

The properties which are decisive in determining the steady conditions of stability consist for motors of the alteration in speed with the torque $n = f(M)$, and in generators the alteration of the voltage with the current $E = f(I)$. That these two functions correspond to one another is clear from the expressions of power

in a motor $P = 0{,}00103\ n\ M$

and in a generator $P = 0{,}001\ E\ I$.

In a D.C. motor the torque (M) is, by the way, proportional to the product of the armature current (I) and the flux (Φ). In shunt motors the flux is, practically speaking, constant, and in series motors is a function of the current. In both cases accordingly $P = f(n, I)$.

In D.C. generators the voltage (E) depends upon the speed (n) and the flux (Φ). The flux is constant or is a function of the current (I), and accordingly in this case also $P = f(n, I)$.

The following symbols are used:

P = Power in kW,
n = r.p.m.,
M, W = Torque in kgm, driving or load,
E, e = Pressure in volts, driving or load,
I, i = Current in amps., driving or load.

The characteristic curves for D.C. machines are shown as continuous lines, and loads are shown in dotted lines.

For D.C. motors the characteristics with constant voltage are in accordance with fig. 1.

One extremity of the curve is the no load speed on the n-axis, and the other lies on the M-axis and is the torque which brakes the motor to standstill. An exception to this is given by a shunt motor with opposing series winding (or large armature reaction) for which the torque decreases from a maximum value to zero at the same time as the speed rises to a very high value. This last case arises when the motor current is so great that the ampere turns of the series winding approach those of the shunt winding, and the flux accordingly approaches zero. In motors which are used in practice, however, this part of the curve is only reached at such high loads that it may be regarded as being of no importance.

For common D.C. motors accordingly the ratio $\frac{dn}{dM}$ is either negative, *i.e.* the r.p.m. de-

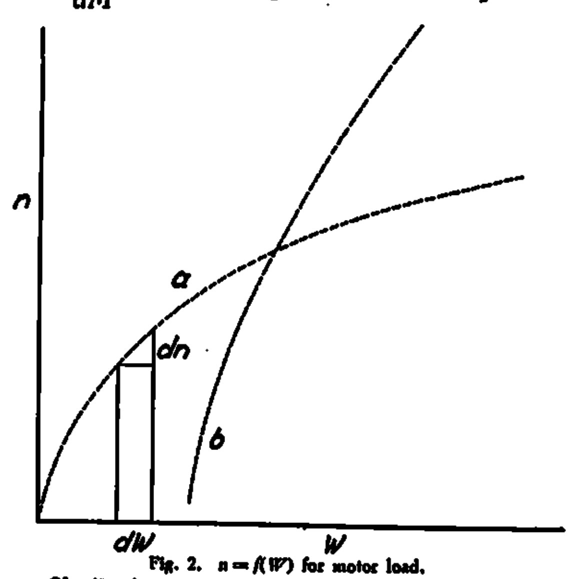


Fig. 2. $n = f(W)$ for motor load.

a. Centrifugal pumps, ventilators etc. b. Machine tools, railway motors etc.

creases with an increase in torque, or becomes zero as a limiting value.

With variable voltage (and constant torque) the speed changes approximately in proportion to the voltage. With a series motor fed from a series generator of similar size (running at constant speed) the voltage rises as the load increases, so that the speed of the motor is maintained constant at all torques (within certain limits).

The motor load is made up of power consuming machines of all kinds. The necessary torque for running them, W, fig. 2, increases more or less with the speed, and is dependent on the fact that friction of various kinds has to be overcome, and this cannot fall with increased speed (under conditions wich are otherwise constant). One extremity of the curve lies on the W axis, and $\frac{dn}{dW}$ is always positive. Curves with apparently negative $\frac{dn}{dW}$ are in practice substitued by small pieces of different curves having positive $\frac{dn}{dW}$.

For a motor to run with a certain load under steady conditions, it is requisite that the motor curve and the load curve shall intersect one another at this point. Before the point of intersection is reached any additional torque on the motor curve is used up in accelerating the masses, and any excess on the load curve in retarding the masses. If the two curves coincide with one another, running is unstable (the load is undetermined). In actual working the curves must not coincide as working then becomes "sensitive", *i.e.* a small alteration in one of the curves introduces a large alteration in the load.

The motor curve A_1 is assumed to cut the load curve B at the point a, fig. 3. If by a small regulation of the motor (for example by decreasing the shunt current in a shunt motor) the motor curve A_1 is altered to another curve A'_1 of the same character as A_1, a torque ab arises which accelerates the masses until a new point of intersection between A'_1 and B is reached at c. At the same time the accelerating torque

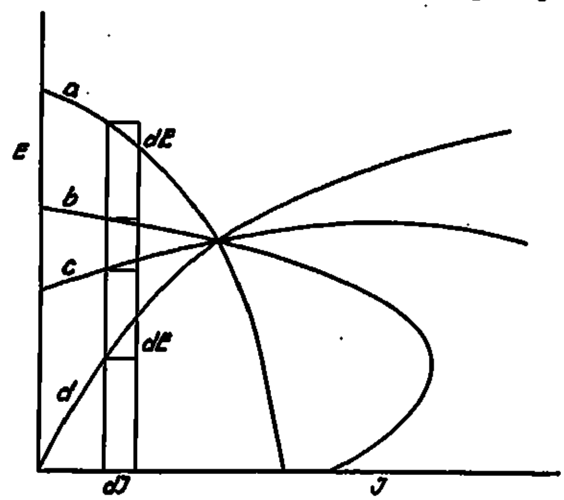


Fig. 4. $E = f(I)$ for various generators.

a. Generator with nearly constant current, $\frac{dE}{dI}$ negative. b. Shunt generator. c. Overcompounded generator. d. Series generator $\frac{dE}{dI}$ positive.

decreases to zero at c and working is then stable. The conditions are analogous if the new motor curve lies somewhat lower, or if the corresponding alterations are made in the load curve B.

It is of interest to investigate the stability with different kinds of motor curves. In the case just referred to $\frac{dn}{dM}$ was negative; $\frac{dn}{dW}$ is, as stated above, always positive. If $\frac{dn}{dM}$ was positive and $< \frac{dn}{dW}$, curves A_2 in fig. 3, an alteration of curve A_2 to A'_2 entails an accelerating torque ab, and since the rotation must always take place in the same direction as the power the speed will increase. As, however, no new point of intersection between A_2 and B can occur in this direction, the motor will race, *i.e.* speed and accelerating torque increase more and more. If the motor curve A'_2 lies above A_2, there is a retarding torque, and since no new point of intersection can be obtained in this direction either, the motor will pull up. Thus, in this case working is unstable, and for this reason the use of a motor with positive $\frac{dn}{dM}$ should be avoided (*i.e.* with opposing series

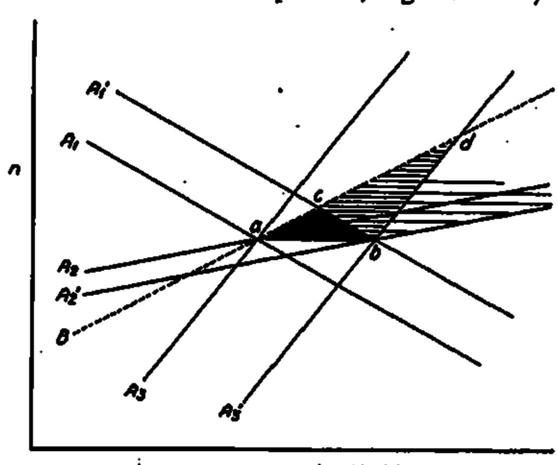


Fig. 3. Various Motors (A) on load (B).

winding, high armature reaction or heavy overload on ordinary shunt motor).

If $\frac{dn}{dM}$ was positive and $> \frac{dn}{dW}$, the curve A_3 in fig. 3, it is obvious that a new point of

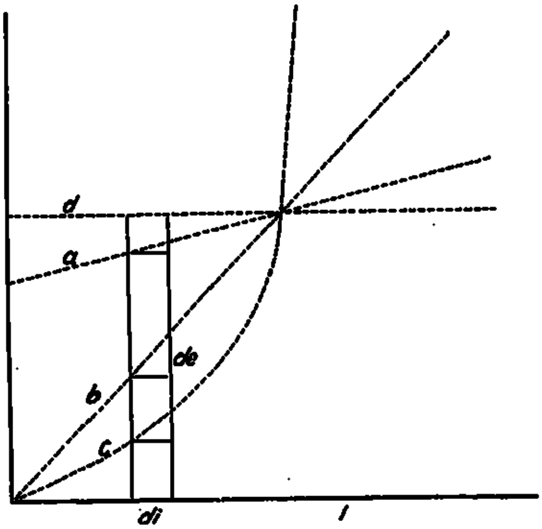


Fig. 5. $e = f(i)$ for generator loads.
a. Charging accumulator battery. b and c. Resistance. d. Large network.

intersection would be obtained between the curves A'_3 and B at d, and working would certainly be stable. But for this case such a motor must have a particularly large $\frac{dn}{dM}$ (which in addition on lightload would easily vary so as to become $< \frac{dn}{dW}$) so that this particular case is of no great practical importance.

The requirements for stable running can be expressed by the following:

$$\frac{dW}{dn} - \frac{dM}{dn} > 0.$$

The characteristics of generators at constant speed are in accordance with fig. 4. One end of the curve is the no load voltage on the E-axis, no current being given out. The other end is the short circuit current on the I-axis where the resistance of the load is zero and the current is determined by the voltage induced by the remanent magnetism (taking into account armature reaction and series windings) and the internal resistance of the generator.

The characteristics of the driving motors which are used for running generators also have an influence on the generator curves. Since their speed falls more or less with increased torque, it will be seen that in the curves given above this condition is also included.

The generator load electrical characteristics are shown in fig. 5. For all curves $\frac{de}{di}$ must be positive, since no current can flow in a conductor without an e.m.f. acting in the same direction. The limiting value $\frac{de}{di} = 0$ is possible, and corresponds to the case where a small generator is paralleled on to a system on which large generators are already at work maintaining the voltage practically speaking constant. One end of the curve lies on the e-axis, and the other disappears at $+\infty$. (An exception herefrom is the combined load curve which has negative $\frac{de}{di}$ and which occurs in the parallel running of series generators, see fig. 17, curves $B—A_2$).

If a generator supplies current to a certain circuit, steady conditions are obtained at the point where the characteristic curves of the generator and the load interesect one another. Before the point of intersection is reached, the generator e.m.f. is greater or less than the counter e.m.f. of the load, and the current increases or decreases until a stable condition is reached. During the time that the current is altering, the voltage difference is absorbed in the self induction or capacity of the circuit. If the curves intersect one another at a small angle the running is sensitive, since small variations on the level of the curves, *e.g.* a small increase in voltage may cause a large alteration of the current. In cases where the curves coincide also working is unstable (load undetermined).

The following cases can occur:

1) $\frac{dE}{dI}$ negative, $\frac{de}{di}$ positive. The generator curve A_1 and the load curve B intersect on another at a, fig. 6. If by regulating the generator (*e.g.* by shunt resistance) its curve is

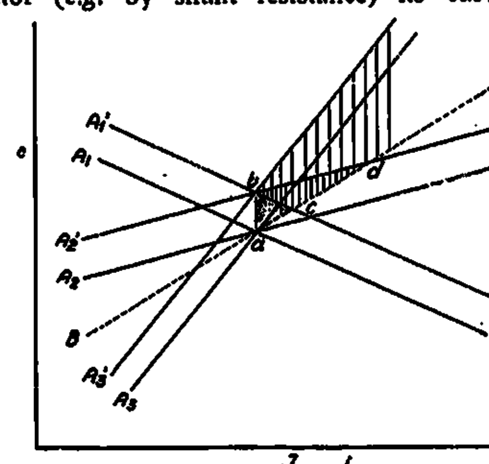


Fig. 6. Various generators (A) on load (B).

altered to A'_1, a voltage difference *ab* arises which endeavours to increase the current until a new point of intersection between A'_1 and B is reached at *c*, and as at the same time the voltage difference decreases to zero at *c*, working is stable. Analogous conditions arise if the generator is regulated in the opposite way or if curve B is shifted. Examples: shunt wound generator used for battery charging or on resistance.

2) $\frac{dE}{dI}$ positive and $< \frac{de}{di}$, curves A_2 and B in fig. 6. If the same procedure is followed we find that here also working is stable, since a new point of intersection is reached at *d*. Examples: a compound wound generator supplying a lighting circuit or a series wound generator connected to a resistance.

3) $\frac{dE}{dI}$ positive and $> \frac{de}{di}$, curves A_3 and B in fig. 6. In this case working is unstable as no new point of intersection between A'_3 and B can be reached in this direction and the voltage difference increases without limit together with the current until "short circuit" occurs. If the generator curve is altered in the opposite direction the current sinks to zero and changes direction, *i.e.* the generator runs as a motor, and working is in this case also unstable. Examples: an overcompounded generator running as a battery charger (the curves can also easily coincide with one another); a series generator either working on a circuit where other generators maintain the voltage constant, or used for battery charging.

These three cases can be summed up in the following expression for stable working:

$$\frac{de}{di} - \frac{dE}{dI} > 0.$$

The load characteristic curve for a *series generator* is in accordance with fig. 7, *abc*. Normally we do not work higher up on the curve than to a point somewhat below the maximum voltage. When the machine is loaded by a resistance with curve B, working is stable at the point *a*

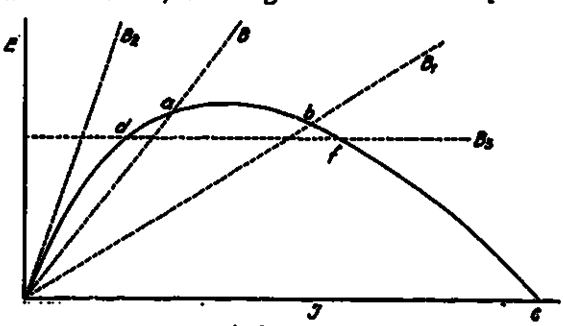


Fig. 7. Series generator.

(case 2 above). With a lower load resistance B_1, working is still stable (case 1) right down to zero resistance "short circuit" point *c*. With greater load resistance B_2 (to the left of the straight part of the magnetising curve), the

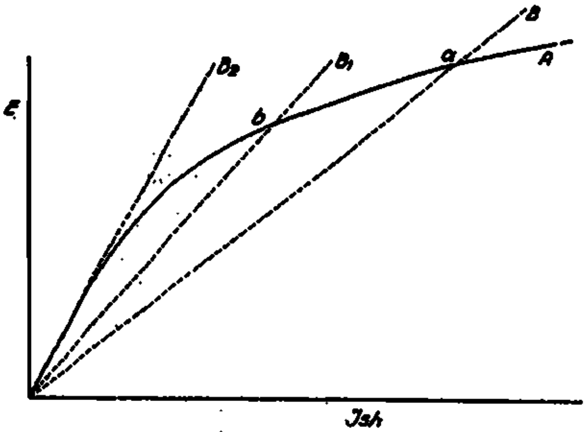


Fig. 8. Shunt circuit for self-excited generator.

generator loses its voltage or is unable to "build up".

If we connect a series generator to a circuit on which larger generators are already working and keeping the voltage constant, this corresponds from the point of view of the series generator to a load curve B_3. Under ordinary conditions (point *d*) working is unstable (case 3) but it becomes stable at the right hand falling part of the curve (point *f*, case 1) which however commonly occurs where the current is so great that the condition is of no practical use. This condition is found in regenerative braking of railway motors by returning power to the supply, which is not possible unless special precautions are taken to stabilise the working.

With *self-excited shunt wound generators* conditions must be stable, not only in the external circuit but also in the shunt circuit. In this last circuit the armature acts like a series generator loaded by a resistance, fig. 8, where A is the magnetising curve of the generator and B the shunt circuit "resistance line" which shows the variation of the shunt current with the voltage when the shunt circuit is of constant resistance. Working is stable at the point *a* (case 2) for the reason that we are working above the "knee" of the magnetising curve. Increase in the resistance of the shunt circuit means that the load curve B is transferred to B_1 and working is still stable at the point *b*. With further increase in the resistance B_2 will coincide with the lower inclined part of the magnetisation curve, working will become uncertain and the generator loses its voltage. Commonly, however,

generators have sufficient remanent magnetism to prevent the magnetising curve falling to zero with zero shunt current, and the appearance is as shown in fig. 9 (when regulating downwards from a higher voltage). Working is then stable right down to a point where the resistance in the shunt circuit is ∞ ($I_{sh} = 0$, point c), although it can happen that the voltage for a small alteration of the resistance is very "sensitive" between the points a and b.

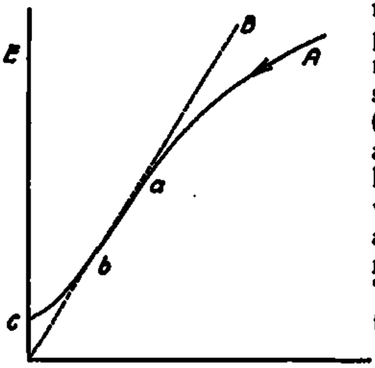


Fig. 9. Self-excited shunt generator with remanent magnetism.

It is interesting to investigate the stability of a self-excited shunt generator with larger load currents and constant resistance in the shunt circuit. Fig. 10 a shows the shunt circuit curves and 10 b the external circuit curves, which last may be easily arrived at from the former. At the lowest part of the bend in the curve working when loaded by a resistance B will be unstable in accordance with case 3. However it is found that working will be stable over the whole curve (at least if the load resistance has small self induction) because the self induction in the shunt circuit is many times greater than that in the external circuit. Thus the current variations in the shunt circuit are very slow, which means that the generator curve before the shunt current has had time to alter has the form A_1 (stable working, case 1). Here, accordingly, it is the "dynamic" and not the "static" characteristic which determines the stability.

A further interesting case is when a *shunt generator feeds an arc* (e.g. electric welding). The characteristic of an electric arc (with metal electrodes) is a nearly horizontal line (B, fig. 11) with a constant length of arc. For stable working the generator must have a drooping characteristic A or A_2 which can be obtained in different ways. The generator can be provided with an opposing series winding (fig. 12, generator curve A); or with a series winding which maintains approximately constant voltage (A_1), the required voltage drop being obtained by an ohmic resistance R in series with the arc c, (fig. 13, generator curve A_2). In electric welding the length of the arc cannot be kept constant, but is subject to continual variations, *e.g.* its length may be suddenly increased, the corresponding curve being B_1. With the first type of generator the voltage cannot vary instantaneously (on account of the selfinduction in the shunt winding and eddy currents in the magnetic circuit) the "dynamic" characteristic is approximately as A_3, and the result is that the current variations are large and the arc is "unsteady". The second generator on the other hand does not require to alter its magnetic condition to any considerable extent, the voltage and current adapting themselves immediately at the point b: the ohmic resistance R exerts a steadying influence on the arc, and welding is better and more even.

We turn now to the question of stability of *two or more generators running in parallel* on the same load. The requirements for this are two in number: first working must be stable when each generator alone carries the load, and secondly working must be stable when one of the generators is regarded as a "generator", and the other generators together with the load itself regarded as the "load". The necessity of the first condition will be clear from the foregoing without further explanation. On applying the second requirement the difference between parallel working of two shunt generators on the one side and of two series generators on the other is seen. The first is stable but not the second, as practical experience also shows.

In fig. 14 two *shunt generators* have similar characteristics A_1 and A_2. The character of the load is shown by B. The curves of the two generators combined give A_1+A_2 and equilibrium is obtained at the point a, were A_1+A_2 cuts B (case 1). The voltage is E_1 and the current I_1+I_2. If one generator is regarded as a "generator", with curve A_1 and the other A_2 together with B as "load" (in which A_2 must be regarded as

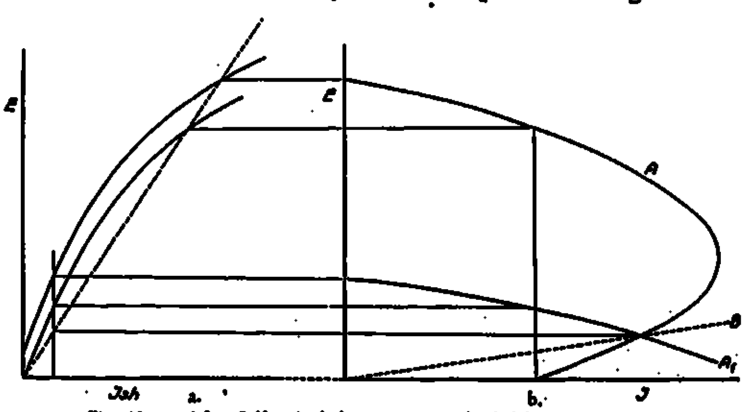


Fig. 10 a and b. Self-excited shunt generator loaded by a resistance.

a load with negative current), the load curve becomes B—A_2 and working is still stable at the point b (case 1). It follows from the form of the curves that when the current falls the voltage rises and vice versa.

If the two generators are of different sizes they divide the current in the same ratio as that of their outputs if the voltage drop between no load and full load is the same for each generator. If they are to divide the load in the same proportion at all loads (and with unchanged position of field regulators), the characteristics must be of the same form. A small dissimilarity in the magnitude of the voltage drop or the form of the curves is not in general of any great importance, since shunt generators are chiefly used where the load only varies slowly, and there is time to alter the position of the curves by adjusting the field regulators and thereby divide the load in the desired ratio between the two machines.

In the parallel running of compound generators (which have shunt and assisting series windings designed to give an increased voltage at increased load), working is unstable. This is so because if both generators should give the same voltage at all loads the distribution of load would be uncertain, and one generator alone could equally well take the whole load or none. Working can, however, be rendered stable by using an equaliser (U, fig. 15) between the series windings. The division of current between the armatures A_1, A_2 is then determined by their characteristics as shunt generators, and the distribution of current between the series windings S_1 S_2 is determined by their ohmic resistances. The equaliser itself should have small resistance. In order that the current should divide in the same proportion even on different loads and with unaltered position of the shunt regulators, it is however necessary that the characteristics of both machines as shunt and as

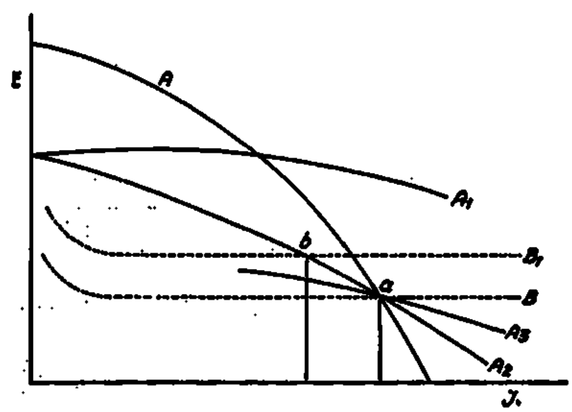


Fig. 11. Shunt generator loaded by arc.

compound generators should be similar, and it is also necessary that the voltage drops in each series winding S between L and U reckoned on the full load current of the corresponding generators should be of equal magnitude.

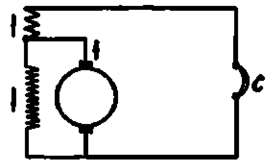


Fig. 12. Shunt generator with opposing series winding.

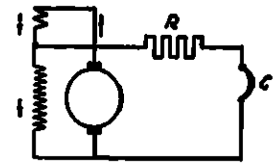


Fig. 13. Shunt generator with assisting series winding and ohmic resistance.

In order to fulfil these conditions the following precautions can be taken. If the generators as shunt machines have small voltage drop or unequal voltage drops between no load and full load, and if this cannot be rectified by shifting the brushes, then opposing series windings (K_1 K_2. KO_1 KO_2 are interpole windings) must be introduced on one or both. These windings must be connected in the circuit between U and J, commonly on the same side of the armature as the other series windings in order to ensure a small voltage between the windings and their connections. (In the case of generators with one pole earthed it should, however, be noted that opposing series windings should be connected between the armature and earth in order to reduce the current surge which occurs in the case of a short circuit of the armature winding to earth).

If the compounding of one generator (*i.e.* the voltage increase obtained by the main series winding from no load to full load) is greater than that of the other, then the number of turns in the series winding must be altered or else a resistance P (preferably with a self-induction equal to that of the series winding) must be connected in parallel with the stronger series winding.

Lastly, if the voltage drop in one of the series windings (taking into account the parallel resistance referred to, if used) with full load current is less than that of the other, then a resistance R must be connected in series with the former so that the voltage drops in both circuits between L and U become equal. In generators where one pole is earthed, the assisting series windings should be connected next to that conductor which is not earthed in order to obviate unnecessarily large current surges in the event of an earth occurring in the armature. The shunt winding (Sh_1 Sh_2) can be connected either directly across the armature or across the outer terminals. In the latter case

the series winding produces a slightly lower voltage increase than in the former case. Ammeters should always be connected in the armature circuit.

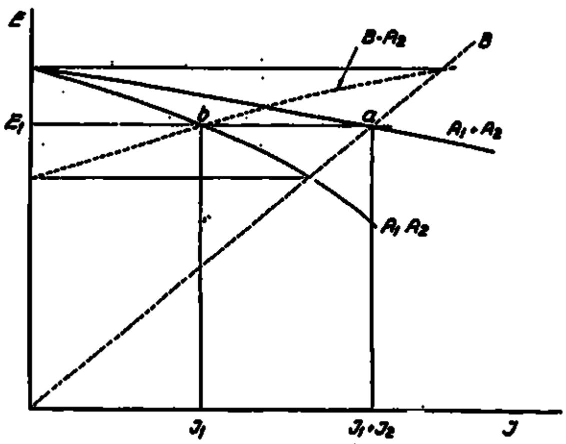


Fig. 14. Parallel working of two shunt generators.

When compound wound generators with sliprings and static balancers are used (for supplying a 3-wire network), the series winding must be divided into two equal parts, one of which is connected on each side of the armature, so that compounding will occur in correct proportion when the load is unequal on the two sides of the system, fig. 16. If two such machines are run in parallel, two equalisers must also be used, one on each side of the armature. In this case also the ammeters should be connected in the armature circuit, since the current in the armature is the current of greatest importance in determining the load on the machine.

Parallel running of series wound generators loaded by a resistance is not stable. In fig. 17 A_1 and A_2 are the characteristics (similar) for the two generators. Their sum is given by the curve $A_1 + A_2$ which intersects the load B at the point a. Here it appears that working

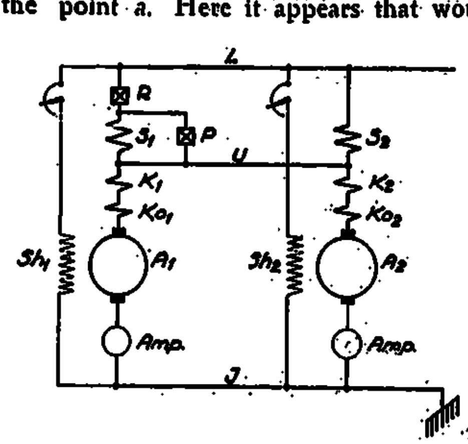


Fig. 15. Parallel connection of compound generators.

should be stable in accordance with case 2. If, however, the other condition for stable parallel working is investigated, viz. with A_1 as "generator" and A_2 and B as "load" (where A_2 is a load with negative current) with curve $B-A_2$, we find that working is unstable at the point of intersection b between these curves. $\frac{de}{di}$ is then negative and the expression $\frac{de}{di} - \frac{dE}{dI}$ thus becomes < 0. We can also express this by saying that when the voltage of A_1 is increased by, *e.g.* increasing the speed of A_1, the current in A_2 increases but decreases in A_1, whereas the reverse should be the case if working were to be stable.

In this case we can use the same remedy which was employed in the case of compound wound generators, viz. an equaliser between

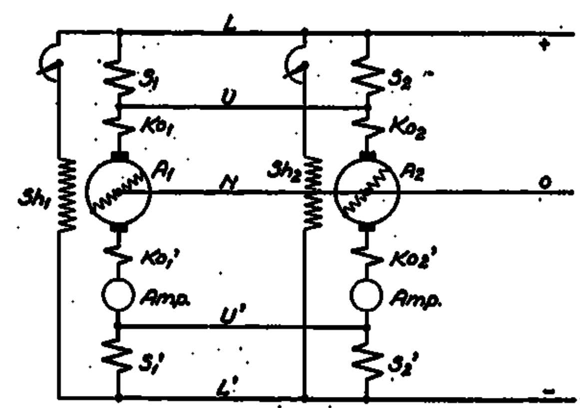


Fig. 16. Parallel connection of compound generators for 3-wire supply.

the series windings. It is still better to allow the armature of one generator to feed the series winding of the other. Both methods are used *e.g.* when series motors on tramcars are parallel connected to a resistance for braking purposes.

Occasionally cases occur where it is desirable *to connect two D.C. motors together mechanically and run them from the same supply.* The requirement for the load and current, in this case being equally shared by the two motors, is that they should have such characteristics that the speed falls with increased load. Shunt wound motors as a rule (at least at higher speeds and in particular where the flux is reduced by shunt regulation) have too small a speed drop between no load and full load, and should accordingly be provided with an assisting series winding, the effect of which is to increase the speed drop. If one motor should take less current than the other, its speed is thereby increased, so that it endeavours to take

over a larger part of the load, entailing a still further increase in current, *i.e.* the motor opposes of itself the variation in current considered. Parallel running is accordingly more stable the greater the speed drop of the motors. No equaliser between the series windings (such as was necessary in the parallel running of compound wound generators) need be used, for in that case the division of current between the series windings would be determined only by their ohmic resistance, and the parallel connected armatures would work as shunt motors and thus with too little speed drop.

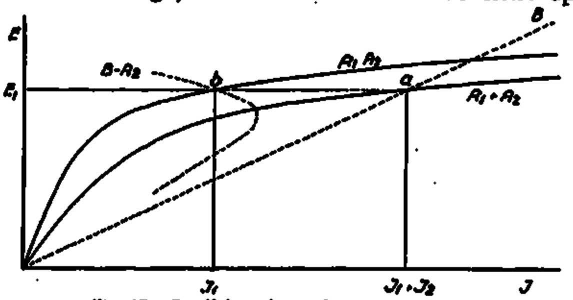


Fig. 17. Parallel working of series generators.

Parallel working of series motors is stable for the same reasons. This arrangement is often used in the case of electric vehicles of various kinds where the characteristics of the series motor make this machine particularly suitable for the working conditions.

E. J. Westman.

THE DESIGN OF STARTING RESISTANCES FOR SINGLE-PHASE INDUCTION MOTORS TO GIVE MAXIMUM STARTING TORQUE.

A single-phase induction motor is normally constructed in the same manner as a three-phase induction motor. Two of the phases act as a running winding, the third phase only being used during starting for the production, by the help of an external resistance, of a field which is out of phase with the field given by the running winding, so that the necessary starting torque is obtained. The resistances which are used may either be non-inductive, inductive, or both non-inductive and inductive, depending on the required starting torque and the allowable starting current.

For small machines — under 2 h.p. — it is usually possible to manage with non-inductive resistance, which is connected as shown in figs. 1 and 2, for Y connected and Δ connected stator windings.

The present article is intended to show how the required ohmic resistance for this method of starting is determined in order that the machine shall give the highest possible starting torque. As single-phase induction motors are usually Y connected, the calculations given have only been carried out for this case, but we also show how the resistance should be determined for a Δ connected winding with the same premises.

The rotor is assumed to have a squirrel cage winding. The effect of the no load current on the current and pressure diagram is neglected, and it follows from this that the short circuit impedance can be calculated in the usual simple manner, and also the power factor on short circuit. Thus expressed generally we have at standstill

$$z = r_1 + jx_1 + \frac{r_2' + jx_2'}{1 + \dfrac{r_2' + jx_2'}{jx_0}}$$

— The meaning of the symbols used is given below — from which the correctness of what we have said above is clear when $\dfrac{r_2' + jx_2'}{jx_0}$ is small with respect to 1.

The following symbols have been used:

E	= Line voltage (volts).
J^I, J^{II}, J^{III}	= Current in stator phases *I, II, III* (amps.).
r	= Starting resistance.
r_1	= Primary resistance per phase.
r_2'	= Secondary resistance reduced to primary winding per phase.
x_1	= Primary leakage reactance per phase.
x_2'	= Secondary leakage reactance reduced to primary winding per phase.
x_0	= No load reactance per phase = $= 24\,\pi\nu\,(q_1 \cdot n_{s1} \cdot f_1)^2 \dfrac{D \cdot L}{\delta'} \cdot 10^{-9}$.
z	= Short circuit impedance per phase. $= \sqrt{(r_1 + r_2')^2 + (x_1 + x_2')^2}$
q_1	= Slots per pole and phase, primary. (Reckoned three-phase).
n_{s1}	= Conductors per slot, primary.
f_1	= Total winding factor, primary.
D	= Air gap diameter.
L	= Length of core.
δ'	= Effective air gap.
ν	= Periods per second.
φ_k	= Phase angle on short circuit ($r = \infty$).

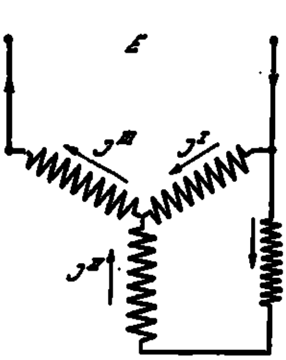


Fig. 1.

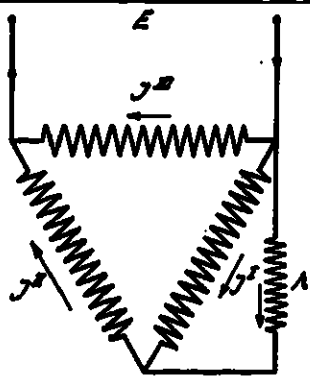


Fig. 2.

φ = Phase angle between E and J^I
φ_2 = " " " J^{II} " J^I
φ_3 = " " " J^{III} " J^I

Resistance in ohms, linear dimensions in cms.

Assuming counter-clockwise vector rotation, the current and voltage diagram at start has been constructed in fig. 3, and for further treatment is expressed in mathematical form in equations 1, 2 and 3.

$$\begin{cases} \dot{J}^{III} = \dot{J}^{I} + \dot{J}^{II} \quad \ldots\ldots (1) \\ \dot{E} = \dot{J}^{III} \cdot z \cdot e^{j\varphi_k} + \dot{J}^{I} \cdot z \cdot e^{j\varphi_k} \quad \ldots\ldots (2) \\ \dot{J}^{I} \cdot z \cdot e^{j\varphi_k} = \dot{J}^{II} \cdot r + \dot{J}^{II} \cdot z \cdot e^{j\varphi_k} \quad \ldots\ldots (3) \end{cases}$$

In addition

$$\begin{cases} \dot{E} = E \cdot e^{j\varphi} \\ \dot{J}^{II} = J^{II} \cdot e^{j\varphi_2} \\ \dot{J}^{III} = J^{III} \cdot e^{j\varphi_3} \end{cases}$$

From these three vector equations all the unknown quantities, with the exception of one, can be found, and it is simplest to select r as a parameter when the remaining quantities can be brought down to quite simple functions of $\frac{z}{r}$ and $\cos \varphi_k$. With the help of the equation for starting torque, the value of $\frac{z}{r}$, which gives the maximum starting torque can be calculated. Unfortunately space does not permit the inclusion of the rather troublesome deduction of the starting torque, and the final formula must be given at once.

With Y connection, the air gap torque is given by

$$M = 2\sqrt{3}\left(\frac{E}{z}\right)^2 \frac{r_2'}{\left(\frac{r_2'}{x_0}\right)^2 + \left(1+\frac{x_2'}{x_0}\right)^2} \cdot \frac{\frac{z}{r}\sin\varphi_k}{4+9\left(\frac{z}{r}\right)^2 + 12\frac{z}{r}\cos\varphi_k}$$

synchronous watts or

$$M = 2\sqrt{3}\left(\frac{E}{z}\right)^2 \frac{r_2' \cdot \sin\varphi_k}{\left(\frac{r_2'}{x_0}\right)^2 + \left(1+\frac{x_2'}{x_0}\right)^2} \cdot f_m \text{ where}$$

$$f_m = \frac{\frac{z}{r}}{4+9\left(\frac{z}{r}\right)^2 + 12\frac{z}{r}\cos\varphi_k}$$

The torque clearly depends partly on the constants of the machine and partly on the value chosen for $\frac{z}{r}$. The numerical value of the factor

$$\left(\frac{r_2'}{x_0}\right)^2 + \left(1+\frac{x_2'}{x_0}\right)^2$$

lies most often between 1.05 and 1.20. The higher the number of poles on the machine and the smaller the machine, the larger this factor becomes.

If f_m is differentiated with respect to $\frac{z}{r}$, and the differential is put = 0, we get the maximum of the torque curve.

$$\frac{\partial f_m}{\partial \frac{z}{r}} = \frac{4+9\left(\frac{z}{r}\right)^2+12\frac{z}{r}\cos\varphi_k - \frac{z}{r}\left[18\frac{z}{r}+12\cos\varphi_k\right]}{\left[4+9\left(\frac{z}{r}\right)^2+12\frac{z}{r}\cos\varphi_k\right]^2} = 0$$

$$\therefore 4+9\left(\frac{z}{r}\right)^2+12\frac{z}{r}\cos\varphi_k = 18\left(\frac{z}{r}\right)^2+12\frac{z}{r}\cos\varphi_k$$

which can be simplified to

$$\frac{z}{r} = \frac{2}{3} \text{ or } r = \frac{3}{2}z$$

The following simple rule can then be stated: the maximum torque is obtained, independently of $\cos\varphi_k$, for

$$\frac{z}{r} = \frac{2}{3}.$$

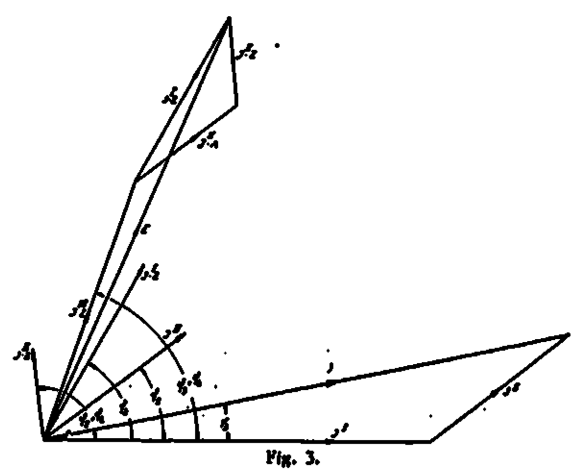


Fig. 3.

It may be mentioned in passing that in deriving the formulae given we have assumed that each phase in the stator and rotor current gives rise to a sinusoidal field (the rotor is assumed to be wound with a three-phase closed winding). The phases combined give rise to a resultant field which can be separated into two fields one rotating to the right and one to the left. Knowing the field strength at a given point and at a given instant, the electromotive forces induced in the rotor phases by the right and left hand rotating fields, can be calculated as a function of the currents in the stator and rotor phases. But the e. m. f.'s induced in the rotor are compensated for by ohmic and inductive voltage drops. In the same way there is no difficulty in expressing the rotor currents as functions of the stator currents, after which, if these last are known, the torque can be calculated with the help of Biot-Savarts law.

Returning to the equations given in the foregoing, we shall next seek to obtain an expression for the stator currents and their phase angles. For determining the magnitude of the starting resistance it is only necessary to obtain particulars as to the ohmic value required and the current which passes through it, but for the sake of completeness and in order to enable us to give a comparison with tests carried out, it will be as well to deduce also expressions for the remaining magnitudes.

From equation 2

$$j''' = \frac{\dot{E}}{z} e^{-j\varphi_k} - J'$$

and from equation 3

$$j'' = \frac{J' z e^{j\varphi_k}}{r + z e^{j\varphi_k}}$$

Inserting this expression in 1 we obtain

$$J' = \frac{\dot{E}}{z} e^{-j\varphi_k} - J' - \frac{J' z e^{j\varphi_k}}{r + z e^{j\varphi_k}}$$

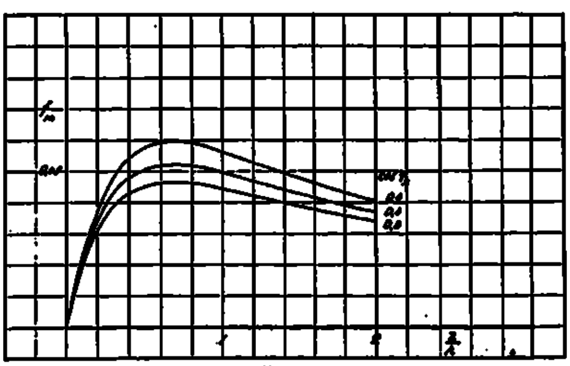


Fig. 4.

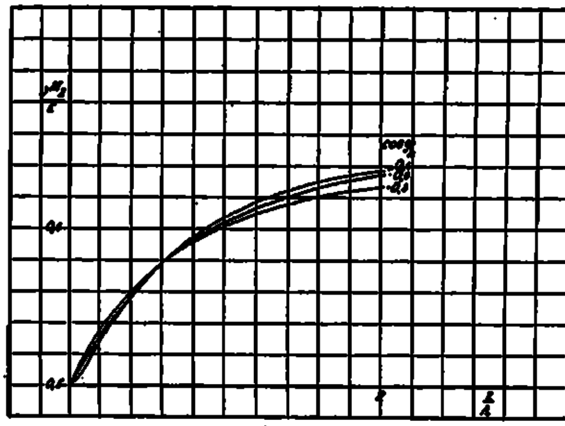


Fig. 5.

and from this

$$z J' [2r + 3 z e^{j\varphi_k}] = \dot{E} [r e^{-j\varphi_k} + z]$$

$$z J' [2r + 3z \cos\varphi_k + j 3 z \sin\varphi_k] = E [(z + r\cos\varphi_k)\cos\varphi + r \sin\varphi_k \sin\varphi] + j E [(z + r\cos\varphi_k)\sin\varphi - r\sin\varphi_k\cos\varphi]$$

$$\therefore \begin{cases} \dfrac{J'z}{E}(2r + 3z\cos\varphi_k) = (z + r\cos\varphi_k)\cos\varphi + r\sin\varphi_k\sin\varphi \quad \ldots\ldots\ldots\ldots \quad (4) \\ \dfrac{J'z}{E} 3z\sin\varphi_k = (z + r\cos\varphi_k)\sin\varphi - r\sin\varphi_k\cos\varphi \quad \ldots\ldots\ldots\ldots \quad (5) \end{cases}$$

Squaring and adding we obtain

$$\frac{J'z}{E} = \sqrt{\frac{1 + \left(\frac{z}{r}\right)^2 + 2\frac{z}{r}\cos\varphi_k}{4 + 9\left(\frac{z}{r}\right)^2 + 12\frac{z}{r}\cos\varphi_k}} \quad \ldots\ldots \quad (6)$$

The phase angle φ is now obtained from 4 and 5

$$\sin\varphi = \frac{\left[2 + 3\left(\frac{z}{r}\right)^2 + 6\frac{z}{r}\cos\varphi_k\right]\sin\varphi_k}{\sqrt{1 + \left(\frac{z}{r}\right)^2 + 2\frac{z}{r}\cos\varphi_k}\sqrt{4 + 9\left(\frac{z}{r}\right)^2 + 12\frac{z}{r}\cos\varphi_k}} \quad (7)$$

$$\cos\varphi = \frac{\left[2 + 3\left(\frac{z}{r}\right)^2 + 6\frac{z}{r}\cos\varphi_k\right]\cos\varphi_k - \frac{z}{r}}{\sqrt{1 + \left(\frac{z}{r}\right)^2 + 2\frac{z}{r}\cos\varphi_k}\sqrt{4 + 9\left(\frac{z}{r}\right)^2 + 12\frac{z}{r}\cos\varphi_k}} \quad (8)$$

In accordance with the foregoing

$$j'' = \frac{J' z e^{j\varphi_k}}{r + z e^{j\varphi_k}}$$

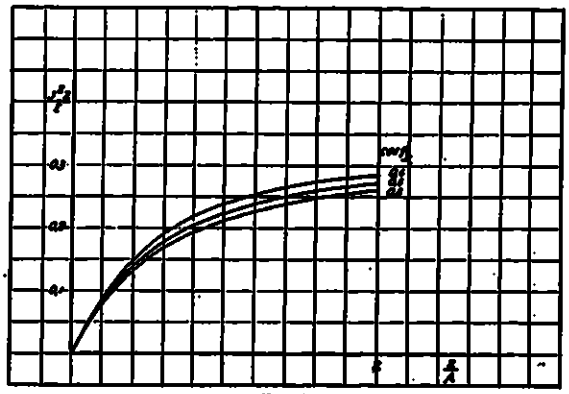


Fig. 6.

Expanding this equation we obtain:

$$J^{II}(\cos\varphi_2 + j\sin\varphi_2) = \cdot$$

$$\cdot\frac{J^{I}z}{r^2+z^2+2rz\cos\varphi_k}[r\cos\varphi_k + z + jr\sin\varphi_k]$$

In the same manner as before

$$J^{II}\frac{z}{E} = \frac{\frac{z}{r}}{\sqrt{4+9\left(\frac{z}{r}\right)^2+12\frac{z}{r}\cos\varphi_k}} \quad \ldots\ldots (9)$$

$$\sin\varphi_2 = \frac{\sin\varphi_k}{\sqrt{1+\left(\frac{z}{r}\right)^2+2\frac{z}{r}\cos\varphi_k}} \quad \ldots\ldots (10)$$

$$\cos\varphi_2 = \frac{\frac{z}{r}+\cos\varphi_k}{\sqrt{1+\left(\frac{z}{r}\right)^2+2\frac{z}{r}\cos\varphi_k}} \quad \ldots\ldots (11)$$

Equation 9 gives us the magnitude of the current in the starting resistance as a function of $\frac{z}{r}$ and $\cos\varphi_k$. The starting current J^{III} now only remains.

We found that

$$J^{III} = \frac{\dot{E}}{z}e^{-j\varphi_k} - J^{I}$$

$$J^{III}z = E[\cos\varphi\cos\varphi_k + \sin\varphi\sin\varphi_k +$$
$$+ j(\sin\varphi\cos\varphi_k - \sin\varphi_k\cos\varphi)] - J^{I}z$$

and from this we obtain

$$\frac{J^{III}z}{E} = \sqrt{\frac{1+4\left(\frac{z}{r}\right)^2+4\frac{z}{r}\cos\varphi_k}{4+9\left(\frac{z}{r}\right)^2+12\frac{z}{r}\cos\varphi_k}} \quad \ldots (12)$$

$$\sin\varphi_3 = \frac{\frac{z}{r}\sin\varphi_k}{\sqrt{1+\left(\frac{z}{r}\right)^2+2\left(\frac{z}{r}\right)\cos\varphi_k}\sqrt{1+4\left(\frac{z}{r}\right)^2+4\frac{z}{r}\cos\varphi_k}} \quad (13)$$

$$\cos\varphi_3 = \frac{1+2\left(\frac{z}{r}\right)^2+3\frac{z}{r}\cos\varphi_k}{\sqrt{1+\left(\frac{z}{r}\right)^2+2\frac{z}{r}\cos\varphi_k}\sqrt{1+4\left(\frac{z}{r}\right)^2+4\frac{z}{r}\cos\varphi_k}} \quad (14)$$

As it is interesting to see how torque, starting current and "resistance current" vary, we have expressed these magnitudes in curve form in figs. 4, 5 and 6.

We have already found that if $\frac{z}{r} = \frac{2}{3}$ the machine under consideration develops maximum starting torque. In practical calculation we accordingly have only to make $r = \frac{3}{2}z$, and from the curves in figs. 5 and 6 read off the starting current and "resistance current". As these vary to an inconsiderable extent with $\cos\varphi_k$, and as these power factors themselves with machines which can be started in this manner remain fairly constant — in the neighbourhood of 0.7 — the currents can be obtained in the following simple, and for all practical purposes exact, manner:

resistance current $J^{II} = 0.18 \cdot \frac{E}{z}$

starting current $J^{III} = 0.58 \cdot \frac{E}{z}$

If the take $\left(\frac{r_2'}{x_0}\right)^2 + \left(1+\frac{x_2'}{x_0}\right)^2 = 1.15$ and as before $\frac{z}{r} = \frac{2}{3}$ also $\cos\varphi_k = 0.7$, the torque equation is simplified to $M = 0.105\left(\frac{E}{z}\right)^2 r_2'$ synchronous watts. This equation should only be regarded as an

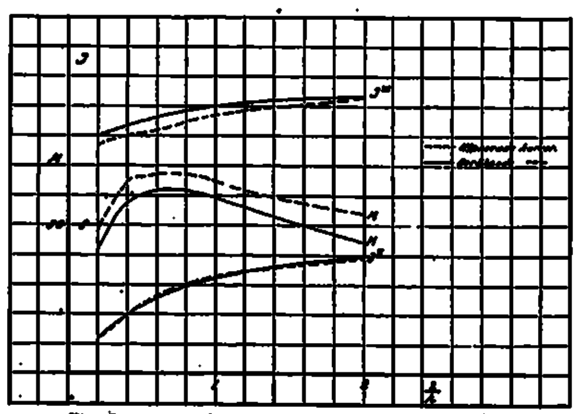


Fig. 7. ------ Test curves. —— Calculated curves.

approximate formula since the error which may arise, due to departures from the assumptions made, may in certain cases reach 15 %.

If the stator winding is Δ connected it can easily be shown that if $\frac{z}{r} = 2$ the starting torque is a maximum, and of the same value as if the machine were Y connected and $\frac{z}{r}$ made equal to $\frac{2}{3}$, *i.e.* $\frac{r_\Delta}{r_Y} = \frac{1}{3}$. The "resistance current" and the starting current are both three times as great as the respective currents with Y-connection, presupposed, that the line voltage is the same at both connections.

From a test carried out on a motor type MK 5, No. 211189, 1/8 h.p., 110 volts, 50 cycles, 1,380 r.p.m., we have lastly in fig. 7 given a curve showing maximum torque in the air gap, starting current and "resistance current" as a function of $\frac{z}{r}$, and for the sake of comparison we have shown also the calculated values of the same quantities. The departure from the calculated current curves is particularly small, and this is also borne out by a number of other tests. In this case it does not exceed 5 %. As regards the torque curves, the similarity between them is clearly shown. With greater values of $\frac{z}{r}$ the curves obtained on test, however, rise slowly relative to those calculated, due to the increased heating. For the same reason the absolute amounts are not exactly commensurable. The calculated curves hold for a constant temperature of 15°C in the rotor winding, while the temperature during test is variable, the mean value being probably in the neighbourhood of 60°C. To make the curves comparable, this means a reduction of the torque measured to 84 %, and the greatest departure from the measured value of the torque is then found to be 8 %.

The starting torque of a motor is of course determined, not by the maximum but by the minimum torque, *i.e.* the lowest torque obtained with any rotor position. The relation between these torques depends chiefly on the design of the rotor, whether the slots are insulated or not, the inclination of the slots, the air gap, and also to some extent on the absolute magnitude of the starting torque. As with uninsulated slots currents can flow in any direction through the rotor plates, and as this condition, especially with single-phase machines, can lower the starting torque to a considerable degree, the practice in Asea is always to furnish squirrel cage rotors for single-phase with slot insulation. It has been found on test that the minimum torque in general is about 85 to 95 % of the maximum torque.

In the manner given above we can also calculate in advance the starting resistance currents, in a surprisingly simple, but none the less accurate manner. Unfortunately the method does not hold good for all cases. Experience shows namely that with 2-pole machines departures from the values calculated in this way may be large. The reason for this is the presence of harmonics in the field curve, which on account of the fact that the relation between the air gap and the pole pitch is relatively small in a 2-pole motor, can play a much more important part than they can in a machine with a number of poles. With such machines the best method is to determine a suitable starting resistance by trial and error on test.

V. Olander.

ASEA IN NIGERIA.

BY *JOHN F. SHIPLEY*, M.I.E.E.

Asea is now a household word in countries abroad, and is met with in the most remote and undeveloped places. Asea's connection with Nigeria is due to tin mining, which is a 20 year old development in the Northern area of that country. Asea is connected with tin mining in other parts of the world, such as the East Indies, Malay States, and particularly in Bolivia, but whereas each of those countries contributes over 20 % of the world's production, Nigeria only produces 5 %, and is therefore relatively

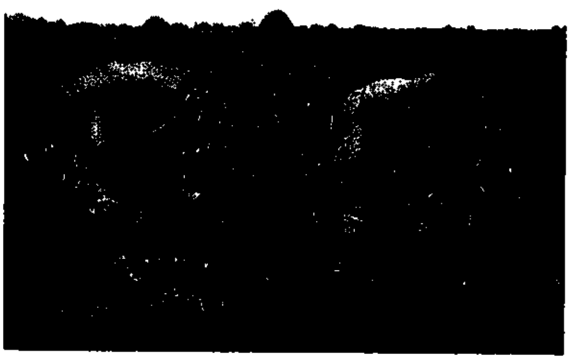


Fig. 1. Native Pagans.

unimportant. But Nigeria is new, and it is safe to say that the first electrically driven mine there having chosen Asea's material, other mines will copy and the good name go on. At any rate, the first two mines to be equipped electrically have both patronised Asea, and have sent repeat orders.

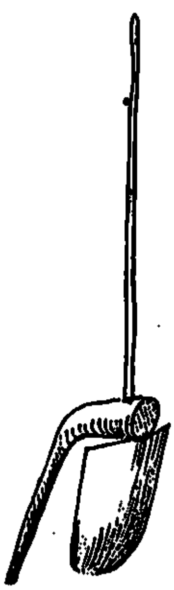


Fig. 2. The pagans' iron spade. (Sketch by the author.)

That portion of the plateau in Northern Nigeria from whence most of the tinstone comes, is a granite formation now covered with detrital and eluvial deposits, roughly 2,000 square miles in extent. Intrusion into the older rocks of the mineralised granite and subsequent erosion, has occurred in previous ages, and the broken down and decomposed material, together with all its contents, has been washed down into the old river beds, and buried beneath deposits of clay and gravel, or sometimes deposited on top of them. New streams now flow, often but not always, in the old beds.

The lodes in the granite contained cassiterite or tinstone, and these lodes were broken down and the heavy tinstone washed downstream with the rest, but owing to its weight it worked down to the bottom and now remains in pockets

Fig. 3. Extracting tinstone by ground sluicing.

and on ledges covered by an overburden varying in depth from 7 to 70 feet.

In all countries where alluvial tin is found the climatic conditions are toublesome, and the conditions are usually of the worst. Alluvial mining may be described simply as shifting dirt on a large scale, and this needs especially robust plant. For these reasons, Asea material has been chosen because it is essentially robust and enduring, while economic as regards cost.

Mining on the Nigerian plateau is wholly alluvial, and the tinstone is extracted from the tin bearing gravel in five different ways, embodying practically every process known to the alluvial miner, as follows:

a) By panning in calabashes handled by natives in the stream beds.

Fig. 4. Pumping tin bearing gravel.

b) By ground sluicing, where the lie of the land and flow of water permit.

c) By breaking down the deposit with the hydraulic jet and pumping the wash thus obtained by gravel pumps.

d) By using a power driven shovel to dispose of the overburden and deposit, and

e) By dredging, either by bucket dredges or by suction cutter dredges, depending upon the character of the deposit.

With the exception of (d) all these methods are used on the two mines, those of Ropp Tin Ltd. and of the Northern Nigeria (Bauchi) Tin Mines Ltd., whose equipment, supplied to a great extent by Asea, is illustrated in this article.

Method (a), that of calabashing, is not illustrated, but is carried on in all the mines by

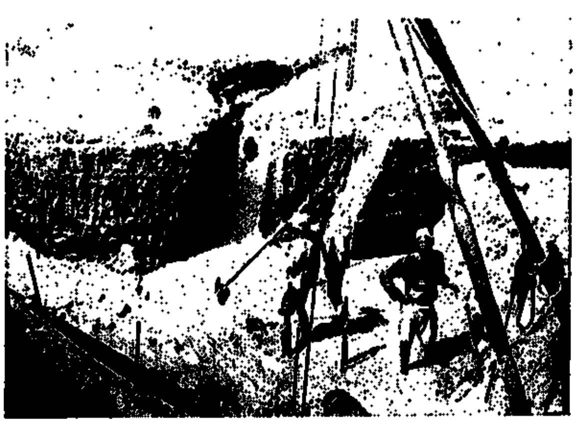


Fig. 5. Sump with tin bearing gravel on clay bed.

Pagan tribesmen, who are the original occupants of the land and strong capable people. The tribes are self-supporting and localised, and retain their economic life by hard agricultural work. They do not take kindly to labour other than for tribal requirements, hence labour is scarce and there is competition for it. Consequently, the use of machinery, and especially electrically driven machinery, is developing. The two Pagans shown in fig. 1 are tilling the ground with iron spades, fig. 2, forged by themselves from local ironstone (associated with tinstone), smelted by themselves entirely without the aid of the white man.

Method (b), ground sluicing, is in use on many mines, and is the most economic as it needs no machinery. Then sloping tin ground is divided into sections and cut out by spade labour and dumped into long sluice boxes on the ridge dividing two paddocks. Water, running naturally along the top of the banks, is led down these sluice boxes so that the gravel, *etc.* is carried down and riffles on the bottom of

Fig. 6. Sluice boxes for recovery of tinstone.

the sloping boxes catch the tinstone. They are regularly cleaned out and the tin extracted, washed and shipped for smelting.

Fig. 3 shows ground sluicing being carried on; the little pump shown in the picture is for drainage, and is driven by an Asea motor.

Method (c), gravel pumping, is illustrated in fig. 4, which shows a paddock on the property of the Northern Nigeria (Bauchi) Company, which has been wholly excavated by using the gravel pump. The picture shows the barren overburden, about 60 feet thick, under which about 2 feet thick of tin bearing ground has been exposed, and is being washed down by two hydraulic pressure jets. The wash runs down the gullies cut in the stiff clay on which the tin deposit lies, as shown i fig. 5, to the sump from whence it is pumped by a centrifugal gravel pump (mounted on the stationary pontoon) up to the bank, whence it runs down the inclined gutter, or sluice box. The tailings run away, and as they do so they are forked, so that the tin drops down to the bottom of the boxes, and is caught by the riffles at the

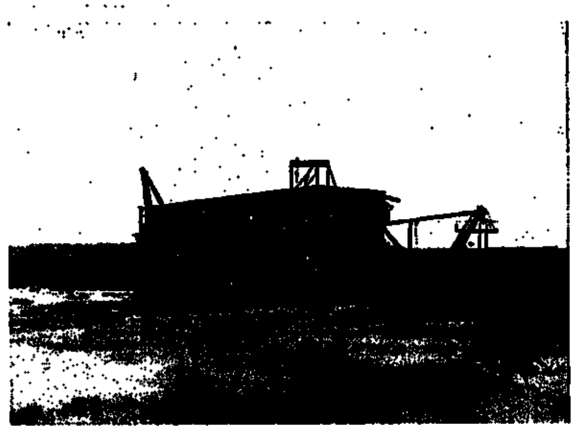


Fig. 7. Electrically operated dredge.

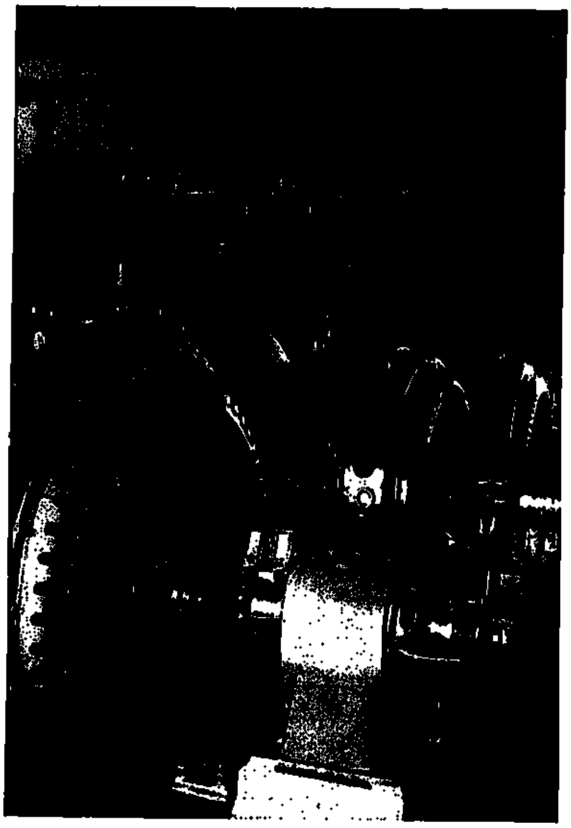


Fig. 8. Ropp Power Station, showing Lighting set.

bottom. These sluice boxes are shown in fig. 6, and the tinstone obtained from the riffles at the bottom is shown drying on the floor in the foreground.

Method (e), dredging, is in use on several mines, and Ropp Tin Ltd, possesses two electrically driven dredges, of which one is illustrated in fig. 7. On the dredge is mounted a complete equipment for cutting out the ground, pumping water to wash the gravel, and to extract the tinstone from the wash on its journey from the buckets through the dredge to the tailing dumps at the back. The machinery on this dredge, the cylindrical sorting drums, the washing boxes, and the water pumps etc. is wholly electrically driven. The Ropp Power Station, fig. 8, contains three Willans-Asea diesel electric generating sets, each giving 250 kW. These sets transmit the power over the transmission lines to the widely scattered working areas, which are continually being shifted and are often several miles apart. A belt driven auxiliary dynamo is useful for giving light in the power house, workshop and camp when the main sets are not working. In the workshop a 15 h.p. motor drives the line shafting, and use is made of the power in many other ways.

The Northern Nigeria (Bauchi) Tin Mines Ltd. are fortunate in having acquired the use of a waterfall, some 12½ miles away from their property, which has been developed, and provides 2,000 kW during the greater part of the year. The power thus obtained has resulted in a great reduction in the cost of mining, and has enabled the company without increase of staff to double the output of tinstone, with highly satisfactory results.

Fig. 9. Kwall Power plant.

In the power house at Kwall, fig. 9, 700 feet below the edge of the plateau, there are four generating sets, of which one supplied by Asea, and developing 500 kW, and driven by a 500 kW Armstrong Whitworth turbine, illustrated in fig. 10. Power is generated here at 550 volts, and stepped up to 22,000 volts for transmission over very rough intervening country

Fig. 10. 500 kW Asea alternator, Kwall.

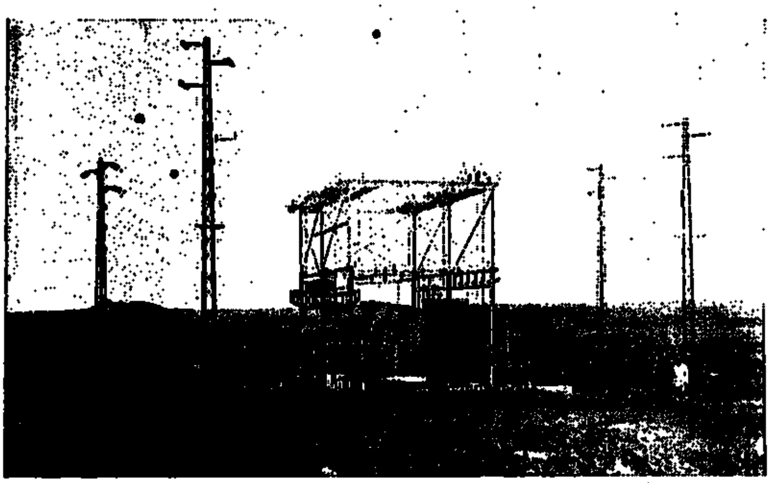


Fig. 11. Open air substation at Bauchi.

to the open air substation shown in fig. 11, which is situated at the strategic centre of the property. It is built for 2,000 kVA, but is equipped at present with two Asea transformers, each of 450 kVA capacity, shown in fig. 12. Here, the power is stepped down 2,200 volts for the large pump motors, while a supply is taken at 400/230 volts for small motors and light.

One of the most important advantages of electric power is the provision of satisfactory lighting during night operations, saving a great deal of tin which would otherwise be lost in the tailings, and preventing interruption of the work.

A further substation has since been erected $2^1/_2$ miles from the main substation on an important tin bearing ground, hitherto worked by oil engine driven pumps. It contains a duplicate 450 kVA Asea transformer.

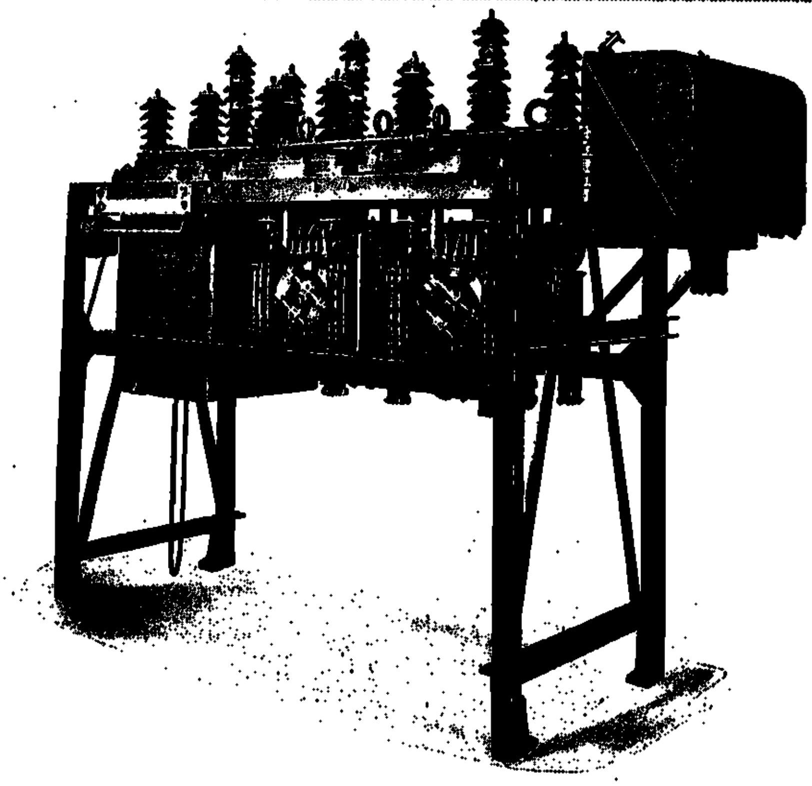
The climatic conditions on the Nigerian plateau are especially severe on electrical apparatus. In winter the air is intensely dry and cold, while the summer is the extreme opposite, being humid and warm to an uncomfortable degree. In the dry season, and as a result of mining operations at all times, a great deal of fine sand is blown into the machinery; while swarms of flying insects at night clog up relays and other sensitive gear. The handling of all plant is of the roughest description, white supervision is necessarily scanty, and the plant is continually being shifted.

In addition severe electric storms are frequent, and the long transmission lines often cause trouble, even though protected by earth lines, and by lightning arresters, because they are used as roosting places by hawks and eagles. In the early morning when the birds' plumage is wet with the very heavy dew frequent shorts are caused, while flying geese and cranes with a wide stretch of wing, often cause short circuits between the phase lines and the earth wire, thus giving rise to interruptions and excess pressure disturbances.

In spite of the abnormal conditions, however, both plants have given great satisfaction, and it is likely that the advantages secured by these two mines, owing to the electrification, will soon be enjoyed by other mines, who now find it desirable to increase their output, and to work poorer deposits, but who cannot do so at present economically owing to the high cost and inflexibility of any other form of motive power.

The author is indebted to the Board of Ropp Tin Ltd., and of the Northern Nigeria (Bauchi) Tin Mines Ltd. for their kindness in allowing him to take and reproduce the photographs shown above.

Fig. 12. Two 450 kVA Asea transformers at open air substation.



VOLTAGE REGULATION

ON POWER NETWORKS.

For obtaining ideal pressure conditions on a power network regulation is necessary in order to compensate the voltage drop in the supply lines, in the step-up and step-down transformers, and in the feeders, and also for suitably distributing the reactive power between power stations running in parallel.

The idea of this regulation is to maintain the voltage at the consumers terminals as nearly as possible constant, to improve the working conditions, to increase the potential quality of the energy distributed, and to increase the transmission capacity of the complete installation.

The most modern method of obtaining voltage regulation is by Asea step-by-step regulators. By means of these regulators, which were used as long as 20 years ago for giving voltage regulation on furnace transformers but have now been redesigned and improved, the voltage can be altered at suitable points on the network in steps of most suitable magnitude either by hand, remote control, or automatically.

Write for our handbook "Voltage Regulation on Power Networks".

ASEA

VESTERAS — SWEDEN

Vesteras 1926, Westmanlands Allehanda Printing Co.

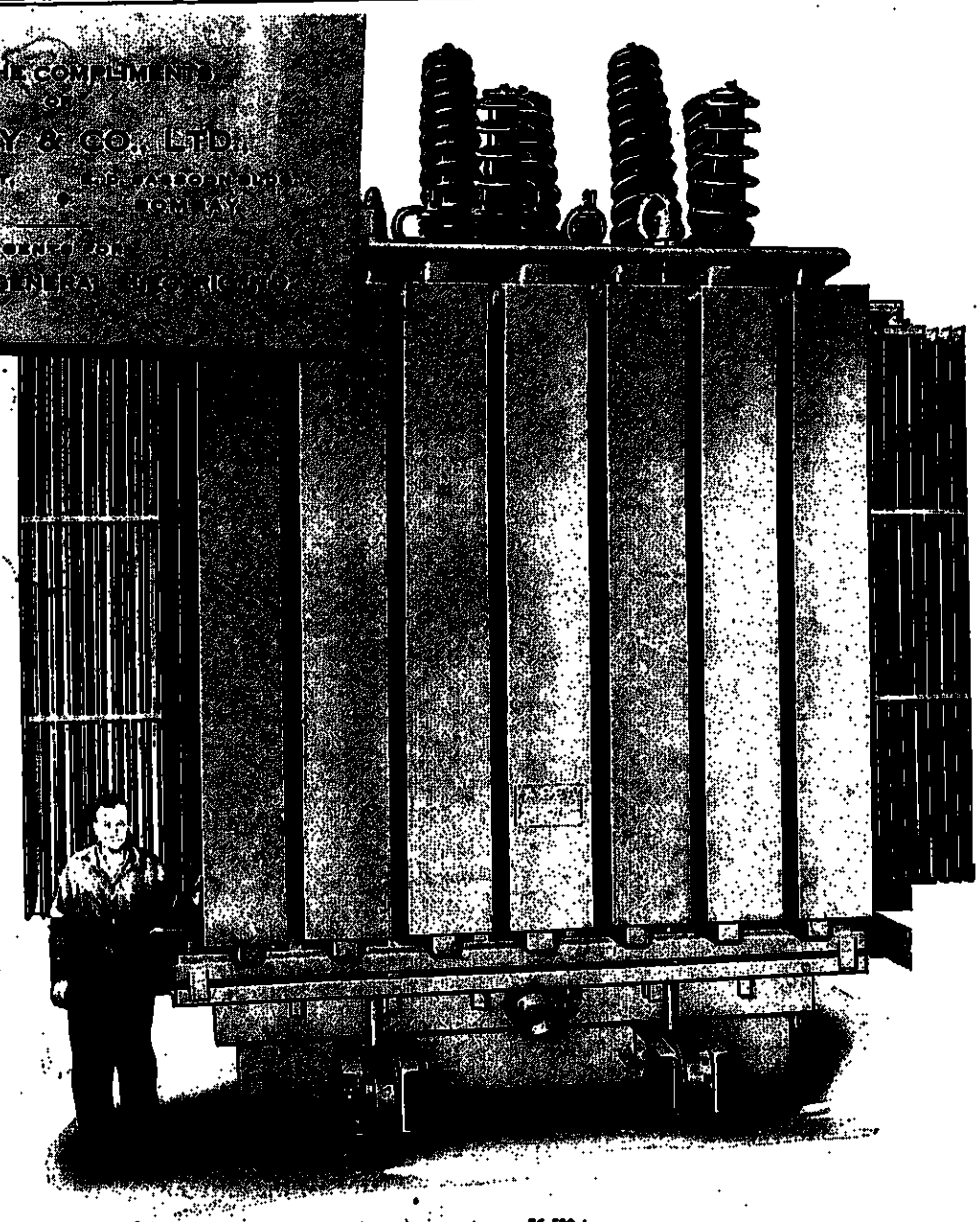
ASEA-JOURNAL

ALLMÄNNA SVENSKA
ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL
ELECTRIC LTD
5, CHANCERY LANE—LONDON

MONTHLY REVIEW

VOL. III 1926	All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesterås, Sweden. Permission is given to reprint articles or extracts from this journal, on condition that the name — Asea-Journal — is clearly stated.	NOV.-DEC. Nos. 11-12



12,000 kVA self-cooled transformer $\frac{56,500}{46,500}$/5,600 volts, 50 periods.

DYNAMOMETERS.

The measurement of *electric power* (*e.g.* kW) is, of course, fairly simple. It is done by the help of a direct reading instrument, which consists in principal of two coils, one fixed and the other moving, and furnished with a pointer. The currents in both coils are very small and proportional respectively to current and voltage, in that part of the circuit in which the power is to be measured. The displacement of the moving coil is practically proportional to the currents in the coils, *i.e.* to the product of voltage and current in the circuit, or the power, and the scale over which the pointer moves can be graduated directly, *e.g.* in kW.

This direct reading instrument has been brought to a very high degree of accuracy and it is so convenient in use that it is very commonly employed. The accuracy with full reading is within from 0.2 to 0.5 %.

The measurement of *mechanical power* (kW, h.p., or kgm per sec.) is not so simple. The mechanical power P is the product of the force F (kg) and the distance per unit of time (m per sec). If the force acts at a radius R (m) on a body which rotates with a speed n (r.p.m.) the power is given by

$$P = \frac{F\,2\,\pi\,R\,n}{60 \cdot 101.9} = \frac{M\,n}{973}\ \text{kW}, \quad (\text{or} = \frac{M\,n}{716}\ \text{h.p.}),$$

where $M = FR$ is the torque in kgm. If the torque and the speed are measured the output

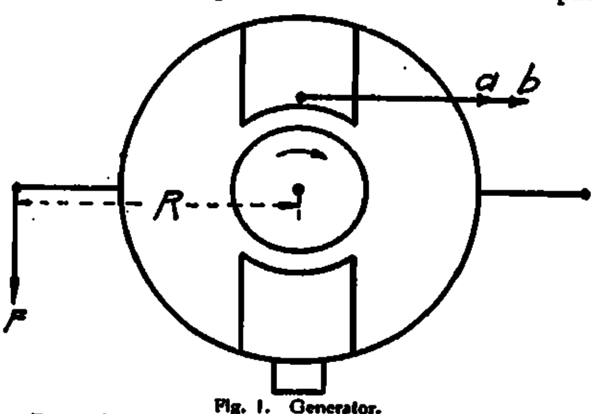


Fig. 1. Generator.
Torque due to a = rotor current, b = losses, FR = weights.

can accordingly be calculated. The torque can be measured by various methods as will be shown below. The speed is nowadays usually determined by a direct reading instrument, which commonly consists of a centrifugal device opposed by a spring. The device is connected to a pointer which gives a displacement proportional to the speed. The accuracy of this instrument is from 0.3 to 0.5 %.

When it is desired to measure the shaft h.p which a steam engine or internal combustion engine gives out, the engine is suitably loaded by a machine which is specially designed for power measurements. Such an arrangement is the *friction brake*, which consists of two brake blocks which are clamped on a pulley fixed to the shaft, and which, on account of the friction at the face of the pulley tends also to rotate. The whole of the power is transformed into heat by friction. If one side of the brake is loaded with a weight F_1 kg, at a radius R_1 m so that the brake is in equilibrium at a certain speed n, the torque due to the weight $F_1\,R_1$ is equal to the friction torque, and accordingly the power absorbed by the brake is $P = \frac{F_1\,R_1\,n}{973}$ kW. In this way the torque is "weighed" and this device might be called a torque balance; as we more usually speak of power, the name *power balance* would perhaps be more suitable than the old name dynamometer. The disadvantage with this arrangement is that the whole of the power is turned into heat and on this account the brake must be made of very large dimensions, or else cooled with water, if it is required for continuous service. The friction cannot be kept constant for a very long time and the readings are accordingly rather uncertain. The arrangement can only be used for small powers up to a maximum of 30 or 40 kW.

Another similar arrangement is the *water brake*, which consists of a container of cast iron with an internal blade arrangement, filled with water, in which a wheel furnished with vanes or buckets and fixed to the engine shaft rotates. The housing tends to take part in the rotation but is prevented by weights in the same way as the friction brake. If arrangements are made for the water to circulate through the brake it is not necessary for the device to be of such large dimensions as the friction brake. Water brakes are made for large powers up to about 3,000 kW. If the shaft is carried in separate pedestal bearings a correction for the friction in these bearings must be made.

If the engine is loaded by an *air brake*, which consists of fan blades or plates fixed to arms on the shaft and against which the air exerts resistance during rotation, it is necessary first to make special measurements with a motor the power of which is known, so that the power necessary to drive the air brake at various speeds can be determined. A correction must be applied on account of the variations of the bearing friction and of the air temperature and pressure. This arrangement is not properly speaking a

"power balance" unless the driving engine or motor is itself supported in a manner allowing it to turn so that, due to reaction, it can be subjected to a displacement in the opposite direction to the direction of rotation and the torque measured directly by the application of weights. Such an arrangement is sometimes used for testing aeroplane engines which are then loaded by means of the propeller belonging to the machine.

Probably the most common method of measuring the power given by an engine or motor is to couple it to an *electric generator* the losses of which are known, and for which the power given out can be determined by electrical measuring instruments. The various stray load losses in the generator cannot be fixed with any great accuracy and in order to calculate the resistance losses the temperature of the windings must be known. An error of 5° in the temperature measurement amounts to approximately 2 % on the resistance losses and possibly 1 % on the total losses of the machine. A greater accuracy than from 1 to 2 % cannot accordingly be obtained by this method, but there is the great advantage that the energy can be recovered, returned to the supply and employed on useful work.

If it is required to measure the power taken by a pump, fan, machine tool, *etc.*, there must be a motor of some kind or other to drive it. The most usual choice — for reasons which will be easily understood — is an *electric motor*, the power supplied being measured and the losses calculated from measurements made at no-load. This does not permit of any greater degree of accuracy than as stated above.

In the two last mentioned cases the electric machine is not used as a "power balance". *If, however, the stator is flexibly supported* the torque can be measured by using weights, the advantage is gained that the method is practically independent of any losses occurring, and the accuracy is consequently increased. In constructing such an *electric dynamometer*, it is, however, necessary to take into account a number of conditions in order that the result may be the best possible, and this will be dealt with in the following.

When the rotor in a D.C. generator for example is rotated and loaded, it reacts upon the stator, so that this also attempts to take part in the rotation. If this is prevented by the stator being provided with feet which stand upon a bedplate, this reaction appears as an increased pressure between one foot and the bedplate. If the feet are removed and the stator hung in a suitable manner in trunnions so that it can turn about the centre line of the shaft of the machine, the pressure or torque can be measured by means of weights hung upon the stator, the effect of which is to oppose the above reaction and maintain the stator in equilibrium in the same position as before. In an electric motor the stator tends to turn in a direction contrary to that of rotation and the weights must accordingly be placed on the opposite side of the stator to that necessary in the case of a generator.

The torque obtained by this method, is however not exactly equal to that produced or absorbed by the electrical machine because a part of the losses in the machine cause no reaction upon the stator. Considering a D.C. generator, the torques which act upon the stator and tending to rotate it, are the following, fig. 1.

1) When $n_a \cdot \frac{p}{c}$ effective conductors in the rotor at a speed n r.p.m. cut the field under the main poles, the flux being Φ per pole, the e.m.f. which is induced is $E_t = \Phi \frac{n}{60} n_a \frac{p}{c} \cdot 10^{-8}$ volts. p is the number of poles for the machine, n_a is the number of conductors, and c the number of circuits in the armature winding. If a current of I_t amps. flows in each conductor the total current is accordingly $I = c I_t$ amps., the output of the machine in kW

$$0.001\ E_t\ I = 0.001 \cdot c\ I_t\ \Phi\ \frac{n}{60}\ n_a\ \frac{p}{c} \cdot 10^{-8}$$

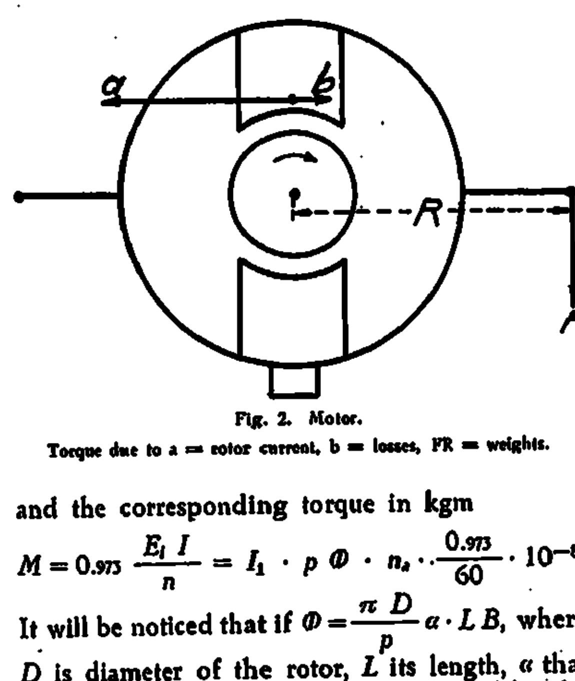


Fig. 2. Motor.
Torque due to a = rotor current, b = losses, PR = weights.

and the corresponding torque in kgm

$$M = 0.975\ \frac{E_t\ I}{n} = I_t \cdot p\ \Phi \cdot n_a \cdot \frac{0.975}{60} \cdot 10^{-8}.$$

It will be noticed that if $\Phi = \frac{\pi\ D}{p} \alpha \cdot L\ B$, where D is diameter of the rotor, L its length, α that part of the pole pitch which is embraced by the pole arc, and B the induction under the pole, then

$$M = I_t \cdot n_s L \cdot B \cdot \pi D \alpha \frac{0.973}{60} \cdot 10^{-8},$$

which is the torque, produced by the current I_1 in a conductor of length $n_s L$ and induction B. This torque acts upon the stator in the direction of rotation, fig. 1a.

2) Iron and friction losses (P_{Fe} and P_{fr} kW) exert a reaction on the stator in the same direc-

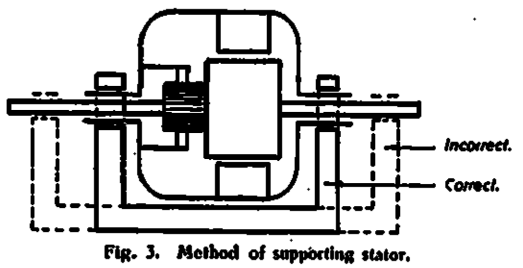


Fig. 3. Method of supporting stator.

tion as the direction of rotation. The iron losses are partly eddy-current losses and partly hysteresis losses. The former are due to currents induced in the iron parts and accordingly have the same action as the currents in a generator winding. The hysteresis losses depend on magnetic friction in the iron and they endeavour to rotate the stator in the same manner as the friction between the rotor and the brushes and bearings, which are fastened to the stator. When the rotor rotates the surrounding air is disturbed and some of it takes part in the rotation, and is being blown against the stator, in the same direction as the direction of rotation. Another part of the air which is in motion does not encounter the stator but is blown against the walls of the room and accordingly gives rise to no torque on the stator. If the two divisions of this air friction are P_{l_1} and P_{l_2} kW the torque on the stator due to this loss $= \frac{973}{n} (P_{Fe} + P_{fr} + P_{l_1})$.

3) Lastly the stator is maintained in equilibrium by the weight F kg at a radius R m. The torque equation on the stator is then

$$I_1 p \Phi n_s \frac{0.973}{60} \cdot 10^{-8} + \frac{973}{n}(P_{Fe}+P_{fr}+P_{l_1}) - FR = 0.$$

If this is compared with the equation which states that the power supplied is equal to the output + the losses, transformed in torque, where M_1 is the torque supplied

$$M_1 - 0.973 \frac{E_t I}{n} - \frac{973}{n} (P_{Fe} + P_{fr} + P_{l_1} + P_{l_2}) = 0$$

we obtain

$$M_1 = FR + \frac{973}{n} P_{l_2}.$$

If the machine runs as a *motor* in the same direction, the load current torque on the stator acts in a direction opposite to the direction of rotation, fig. 2. The torque due to the losses continues to act in the direction of rotation. The torque due to the weights applied acts in the direction of rotation and as it is now the torque produced, M_2, which is to be measured, we obtain

$$M_2 = FR - \frac{973}{n} P_{l_2}.$$

To arrive at the exact torque produced or supplied we must accordingly add a correction to the torque given by the applied weights to compensate that part of the windage which does not react upon the stator. As the windage is greater at higher speeds the magnitude of the correction depends on the speed. If the machine has a fan mounted on the shaft the correction is greater, but if it is totally enclosed the correction becomes zero since in that case the air in motion must always strike some part of the stator. The correction can easily be determined by running the machine alone as a motor at no-load, one side being weighted with F_l kg to maintain equilibrium. The torque due to the weights acts in the direction of rotation and is clearly equal to the windage torque which does not act upon the stator, since the rotor current alone corresponds to all the losses, and accordingly $F_l \cdot R = \frac{973}{n} P_{l_2}$. Measurements are made at different speeds and it is convenient to draw a curve showing F_l in relation to the speed, fig. 4. The magnitude of the windage also depends on the temperature and pressure of the air, but the effect of this on the correction is so small that it may be neglected.

Fig. 4. Correction curve.

Thus the torque to be measured is given by

$$M_{\frac{1}{2}} = (F \pm F_l) \cdot R,$$

where M_1 and + refer to a generator and M_2 and − to a motor. At a given speed the correction is constant and accordingly of greater influence at small loads.

It is not necessary to know the magnitude of the resistance losses, including stray losses. Stray losses arise due to induced voltages in various parts of the machine and are considered

and included in the induced voltage E_i. The magnitude of this is of no importance as it does not appear in the final equation. The temperature of the windings does not accordingly affect the reading. The dynamometer is an application of the axiom that action and reaction are equal and opposite and if this is kept in mind the effect is easy to understand.

The dynamometer is connected through a flexible coupling to the machine, the torque or power of which is to be measured, and the stator must accordingly be supported in pedestal bearings so that it can turn about the axis of the machine. This shaft itself must not rest directly in these bearings as in that case bearing friction losses would arise, which would react on the supporting bearings but not on the stator and would accordingly increase the magnitude of the correction F_f. As the bearing losses may vary under different conditions, this would introduce some uncertaincy into the readings, but this can easily be avoided by carrying the stator directly on the supporting bearings which should be ball bearings so that the dynamometer will move easily. The brush rocker for similar reasons should be fixed to the stator, fig. 3.

On the stator are commonly fixed arms with scale pans in which weights can be placed. The supporting points of the scale pans on the arms should lie in a horizontal plane through the shaft as in that case the measured length of the arms gives the radius upon which the weights act when the dynamometer is in equilibrium in its horizontal position and if the dynamometer should be displaced by a small amount from this horizontal plane the error is small and can be neglected. Should the supporting points not lie in the horizontal plane the length of the radius alters with a displacement of the dynamometer and this must be taken into account. Instead of a simple and cheap arrangement with scale pans, a spring balance can be used, or the arm can act on a cylinder containing some fluid, the pressure of which can be read on a pressure gauge. Registering instruments can also easily be applied to the balance. A sufficiently long pointer should be fitted with a scale clearly showing the position of equilibrium for the dynamometer. In addition the rotor should, of course, be well balanced so that unnecessary vibrations are not caused which would make the readings uncertain. Unequal magnetic pull on the rotor only affects the readings if the resultant of the force does not pass through the centre of the shaft. The cables which carry the current to the stator must be flexible.

For the dynamometer to be stable the centre of gravity must fall below the point of suspension, and as the stator is better manufactured quite circular and without feet, an extra weight is generally placed on the under side of the stator. The dynamometer is so adjusted that when the pointer is on the zero and the supporting points of the scale arms lie in the horizontal plane, the centre of gravity lies vertically under the point of suspension. With a displacement from the horizontal position regard

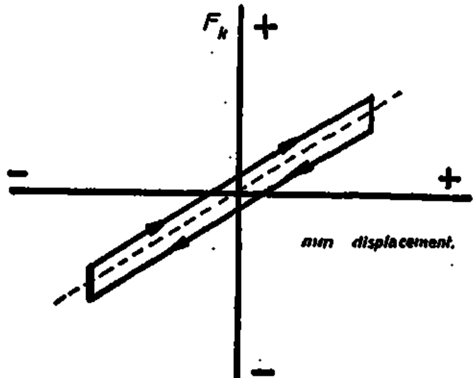


Fig. 5. Correction curves.

must be given to the moment of the centre of gravity about the axis. This moment can be measured by loading first one and then the other scale pan when the dynamometer is stationary and measuring the magnitude of the displacement. The magnitude F_k (in kg) of the weights is best plotted in a curve with relation to the displacement (*e.g.* mm) and the curve has one branch when rising and another when falling, fig. 5. If the stator is supported in ball bearings the distance between the branches, which shows the friction in the bearings, is vanishingly small and we can reckon with an intermediate curve which shows the sensitivity of the dynamometer. The torque is given by

$$M_{\frac{1}{2}} = (F \pm F_f \pm F_k)\,R,$$

where + and − for F_f refer respectively to a generator and a motor and + and − for F_k refer to displacement in the direction of rotation with a generator and motor respectively.

The magnitude of the corrections appear from the following readings taken from dynamometers constructed by Asea consisting of normal open machines without fans, fig. 6.

Type	Indicated kW	r.p.m.	Normal load F kg	F_f kg	F_k with 1° displacement in % of F
DK 7	10	1,200	8.1	0	2.9
		3,000		0.25	
DK 8	12	1,000	16.4	0.06	
		3,000		0.15	
DK 9	8	500	15.6	0	
	32	3,000	10.4	0.29	

The correction for windage is thus so small with these machines that up to 3,000 r.p.m. it can be neglected in practical measurements, at least at full load.

The correction for a displacement from the zero position is not great when we consider that 1° displacement corresponds to 5 mm with a very short pointer which in working can be set to within about 1 mm, and also that the sensitivity can be increased by decreasing the weight which is fixed beneath the stator. The friction in the ball bearings supporting the stator, or the space between the rising branch of the curve and the mean value for F_k is 0.15 % of F. The method can accordingly be considered to be as accurate as an electric measuring instrument.

In order to simplify calculations in practical use the scale arms are commonly made of such a length that $\frac{2\pi R}{60 \cdot 101.9}$ is $\frac{1}{1000}$ or some such even fraction, so that the expression for power is simple, *e.g.* $P = \frac{Fn}{1000}$, where F is the corrected value of the weights in the scale pan and n the r.p.m.

Naturally an A.C. machine can be used as a dynamometer equally as well as a D.C. machine. The advantage of using a D.C. machine is that it can return power to the supply at different speeds whereas the A.C. machine can only act regeneratively at a speed corresponding to the frequency of the supply. In addition, when running as a motor, the speed of the D.C. machine can be regulated within wide limits by simple and cheap arrangements.

The electro dynamic "power balances" have been very widely used in recent years. They are particularly suitable for testing internal combustion engines of all kinds. If the stator is fixed and the dynamometer started as a motor with an ordinary starter, the internal combustion engine can then be started in the most easy manner and, by taking measurements of the power supplied, the no-load losses can be tested and bearings and valves run in before the fuel supply is turned on. When the internal combustion engine is running, the dynamometer is loaded by a resistance, or can return power to the supply, which is of importance if the test is a long one; by releasing the stator the power can be measured easily and quickly at any time.

When testing pumps, fans and machine tools of all kinds, electric motors are now very largely used and if the stator is flexibly supported it is easy to measure the power taken. The efficiency of the dynamometer itself, including all stray losses, can be determined if at the same time the electric power supplied is measured.

E. J. Westman.

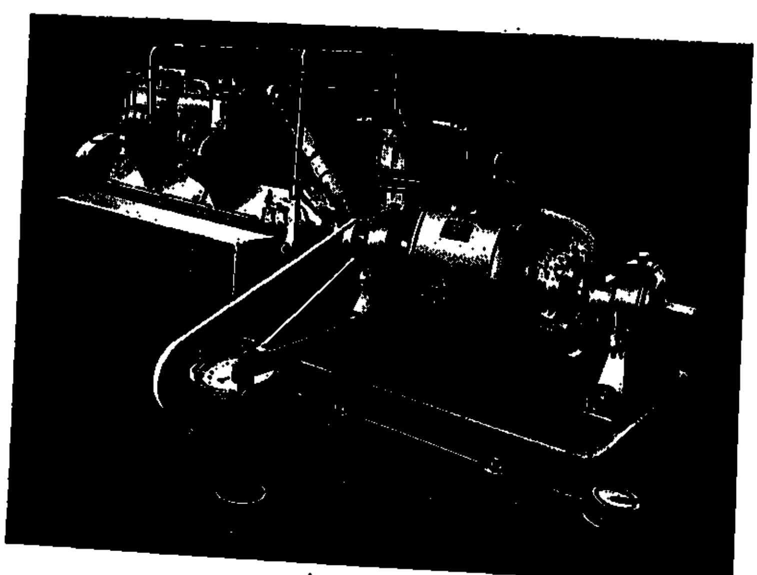


Fig. 6. Dynamometer.

THE NATURE OF BREAKDOWN IN SOLID INSULATING MATERIAL.

Paper read before the third Nordic Electrotechnical Conference in Oslo June 1926.

The nature of breakdown in gases has been fully understood for a long time. The breakdown when it occurs is instantaneous, and in a homogeneous field for any given gas, at a certain temperature and pressure, it takes place at a quite definite field strength and is to be ascribed to impact ionisation of free electrons. (The above rule must be modified to some extent when the field is unhomogeneous or the path of breakdown very small, but there is no need for me to go more closely into this matter).

It was for a long time assumed without any further consideration that breakdown in solid insulating material was of a similar nature to that taking place in gases, and also occured as soon as the field strength overstepped a certain critical value. Curiously enough, it appears that this primitive conception of an exceedingly important question, both from the practical and theoretical point of view, seems to have been exclusively believed on the continent, in England, and in America until quite recently.*)

The question rested at this point, when K. W. Wagner in a most notable paper read before the A.I.E.E., in 1922, subjected the matter to investigation. Wagner put forward the view that breakdown in solid insulating material was a purely thermal phenomenon. Wagner's paper awakened the greatest attention and was quickly followed by a number of publications dealing with theoretical and experimental investigations by various well-known scientists, chiefly in Germany and America. Among these must be mentioned Hayden and Steinmetz, Clark, Rogowski, Günther-Schulze, Kármán, Schumann and others. (See bibliography at end).

In the following I wish to give a short account of the historical development of knowledge as regards the nature of breakdown, and point out what at the present time must be regarded as probably most correct.

First of all, however, it is necessary for me to point out that among other opinions held by Wagner his statement that the nature of breakdown was completely unknown up to 1922 is incorrect. In Asea this question long ago received the most careful attention, and ten years since, we had come to a conclusion which is as nearly as possible in agreement with the newest accepted theories when these are subjected to careful examination. I even expressed the conclusions which I had then reached in two articles which appeared in Teknisk Tidskrift, 1916 (see Bibliography). These articles, as far as I can judge have not become known outside Scandinavia and on this account the theories published later by Wagner and others must be considered to have been independently developed.

The investigations which, more than ten years ago, assisted me to bring to life the question of breakdown, consisted of tests on condenser leading-through bushings. It would be difficult to find anything more suitable for investigations of such a nature than paper-insulated bushings for high voltage. The thickness of the material is great, approximately 50 mm, and the specimen acts as a consequence as if it were quite homogeneous, provided one does not confine oneself to very small elements. (Material of this character has been called quasi-homogeneous.) The fault which occurs with most investigations of breakdown lies in the fact that they are conducted on a laboratory scale using very thin test specimens. The lack of homogeneity which is bound to exist in the material then exercises a very large influence and affects the results, making them puzzling and contradictory. When we wish to arrive at the innermost nature of breakdown, it is clearly of importance that all chance causes should be eliminated.

It was impossible to fail to observe at a quite early date, that breakdown in solid bodies was unlike breakdown in gases in that respect that it did not occur instantaneously, but in general required a certain time, this time being longer the lower the voltage existing. In Asea, it has for long been usual to express the breakdown voltage by a so-called time curve, having the time for breakdown as abscissa and breakdown voltage as ordinate. The curve has a falling characteristic and approaches asymptotically to a definite minimum value of the breakdown voltage, which thus corresponds to the pressure which the specimen can withstand continually. Generally it seems as if the reason for this was sought in the unhomogeneous structure of the solid body where parts of different qualities of resistance to breakdown are mixed up together, thus requiring a certain time for breakdown to be fully established, and before which the pressure can eat through the stronger sections.

*) In K. W. Wagner's treatise of 1922, referred to later, the following occurs:

»The nature of the breakdown in solid and liquid insulating materials has up till now remained in complete obscurity.«

and

»According to the prevailing opinion the rupture takes place at the moment when the density of the electrical field exceeds a certain limit at any point of the insulator. This is called the electrical strength of the material and . . .«

When testing thicker specimens, it does however appear incontestably that the whole proceeding is a purely thermal phenomenon. I cannot do better than make one or two quotations from my article of 1916. — »If these (*i.e.* condensor bushings) are subjected to continuous load at a high temperature and with little power behind them, they are heated up further, due to their own losses and on this account the losses themselves increase *etc.*, until the material can be considered to be completely conducting and the voltage of the testing transformer sinks to zero ... No breakdown or damage to the material can, however, be detected and after the bushing has cooled down it can again withstand considerable voltages.» (In general, however, some alteration occurs as the temperature often becomes so high that the material is to some extent carbonised). If the voltage is altered slowly, giving time for a steady temperature condition to be reached for every voltage, the connection between the pressure and losses or current respectively can be represented by a curve in accordance with fig. 1. The large thermal capacity makes it relatively easy to establish even the unstable falling part of the curve. With thin test specimens, as used by most experimenters including Wagner, it is however very difficult and requires special skill. Quoting further: — »The greatest disadvantage with condenser type leading-through bushings, as with all paper leading-through bushings for high voltages, is the low heat resisting quality of the varnished paper. With temperatures from 50° to 100°, *i.e.* the normal working temperature for transformers, the dielectric losses increase enormously, while at the same time the breakdown voltage sinks to a small fraction of the normal. Leading-through bushings are rendered particularly risky by the fact that the losses within the temperature limits in question, are of such a magnitude that they give rise to considerable heating on their own account. In this way the losses are further increased and the temperature rise is still higher, *etc.* An unstable equilibrium is thus reached with a given temperature and even the smallest temperature rise makes any equilibrium impossible on which account breakdown, after some hours must infallibly occur. If we know and can express the losses as a function of the temperature, and know also the heat conducting qualities of the bushing it is then easy to calculate the critical point mathematically.»

At this time I carried out an elementary calculation of this caracter and I am giving this below in somewhat modified form as it will serve to show the character of the phenomenon in a simple manner. The assumption is that the specimen is of such thickness that the temperature variations in it are relatively small, the chief temperature drop occurring between the specimen and the surroundings. We can thus experimentally obtain the total losses as a function of the mean temperature of the specimen

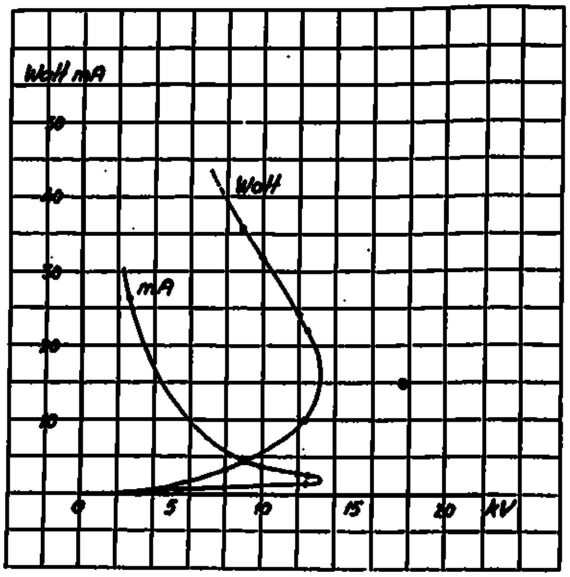


Fig. 1.

reckoned above the surroundings. For field strengths occurring in practice the losses in general are proportional to E^2 where E is the voltage. We can thus put the losses

$$P = \frac{E^2}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where R is the "effective resistance" of the specimen to a current of the frequency in use. R_0 is the magnitude of the resistance at the temperature of the surroundings. In fig. 2 $\frac{R}{R_0} = f(\vartheta)$ is given as a function of the temperature ϑ. Thus the critical point can be calculated.

If the heat conducted away is to be equal to $\mu\vartheta$ we have clearly

$$\frac{E^2}{R} - \mu\vartheta = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

and differentiating

$$-\frac{E^2}{R^2} \cdot \frac{dR}{d\vartheta} - \mu = 0 \quad \ldots\ldots\ldots\ldots \quad (3)$$

from which

$$\frac{R}{R_0} = -\vartheta \cdot \frac{d\frac{R}{R_0}}{d\vartheta} \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

or if the resistance at the critical point is called R_k and the temperature ϑ_k

$$\frac{R_k}{R_0} = -\vartheta_k \cdot f'(\vartheta_k) \ldots\ldots\ldots\ldots (5)$$

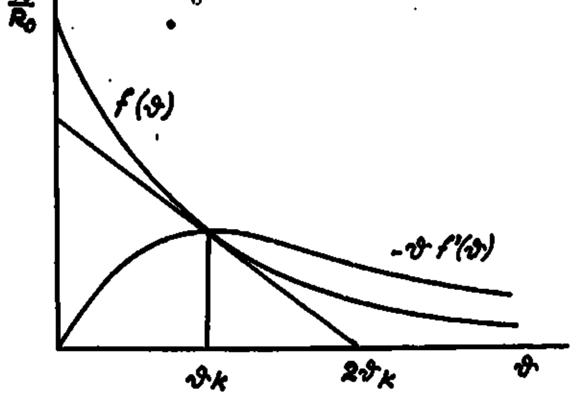


Fig. 2.

If we construct the curve $y = -\vartheta \cdot f'(\vartheta)$ it is clear that this cuts the curve $\frac{R}{R_0} = f'(\vartheta)$ for $\vartheta = \vartheta_k$. The highest field strength corresponding herewith is in accordance with equation (2).

$$E_k = \sqrt{\mu \vartheta_k R_k} \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

From the figure it can further be seen that if $f(\vartheta)$ should actually, over the whole distance, coincide with the tangent at ϑ_k, then R_k would become equal to $\frac{1}{2} R_0$ and in consequence $P_k = 2 P_0$. In practice R_k is somewhat less, or between $\frac{1}{2} R_0$ and $\frac{1}{3} R_0$ so that it follows that $P_k = 2$ to $3 \cdot P_0$. If the losses are so great that they warm up the bushing to such an extent that the losses are multiplied by from 2 to 3, it is obvious that breakdown is certain to occur.

The realisation that breakdown in paper and similar materials was a purely thermal phenomenon lead me immediately to an idea for improving paper leading-through bushings by introducing layers of mica and this is more fully described in the articles already mentioned, and was patented at the same time (mica has a very small temperature coefficient). This has in fact made it possible to use condensor type leading through bushings in transformers where they are subjected to warm oil and high voltages. Another alteration was that the thickness of material in, for example, 80 kV leading-through bushings could be reduced by about 30 % without decreasing the resistance to breakdown. In accordance with equation (8) the critical voltage certainly increases as the square root of R_k and thus with the square root of the thickness, but taking into account the heat drop in the bushing, it will be understood that the critical voltage cannot be raised to any considerable extent by increasing the thickness of the material after a certain limit has been reached. Fig. 3 shows curves made at the beginning of 1916 giving the dielectric losses for 80 kV leading through bushings of bakelite paper with and without mica layers as a funtion of the temperature. Figs. 4 and 5 show curves measured later for condenser type leading through bushings of bakelite paper at different temperatures and for various frequencies. It is important to note that the heat capacity in large paper bushings and insulating material of corresponding dimensions is so great that the bushing will often easily withstand, on a one minute test, more than four times the breakdown voltage for a continous test, a point which all the standard rules for testing have neglected. If a long duration test is required this should be continued for at least 24 hours in the case of large bushings. On the other hand this test can be dispensed with if instead we measure the dielectric losses after having once determined how great these may be to be succesfully withstood by a bushing of any given type.

After this basic rule obtained by experience had been established, a large number of very complete experimental investigations were carried out in Asea's head laboratory regarding the loss characteristics of different insulation materials at various temperatures, and based upon

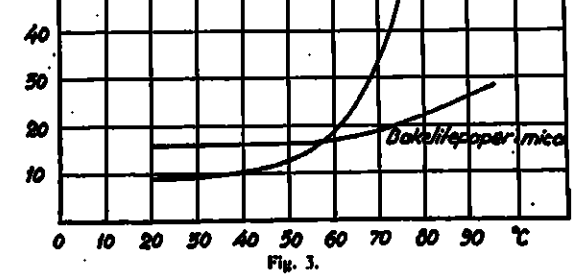


Fig. 3.

these Dr. Dreyfus developed a matematical theory of breakdown, which was first issued as an internal technical report in 1920, and afterwards published in a more fully developed

form in the Teknisk Tidskrift and in the Bulletin des Schweizerischen El. Verein, 1921. These articles covered all parts of the earlier work referred to above.

In making this calculation it is assumed partly, that the temperature of the electrodes is kept constant and equal to that of the surroundings, so that the whole of the heat drop occurs in the test specimen, and partly that a heat drop exists also between the electrodes and the surroundings.

In the former case we obtain:

$$E = k \cdot \Delta^{\frac{n-2}{n}} \cdot \lambda^{\frac{1}{n}}$$

In the above E is the maximum voltage which the specimen can withstand continuously. Δ is the thickness of the specimen in cm, λ is the conductivity in cm $\frac{\text{Watt}}{\text{cm}\frac{\text{C}^\circ}{\text{cm}}}$, watts a constant applying to certain material with a given proportion between specific losses and temperature, n is the power of E by which the losses are increased. With thick specimens which are only subjected to small field strength $n = 2$, and it will be seen that E is independent of the thickness so that among other things it will be noted that an increase in the thickness above a certain limit does not increase the breakdown pressure for the specimens on a test of long duration. As I have already pointed out this agrees well with the results obtained on *e.g.* bakelite paper bushings. With high field strength

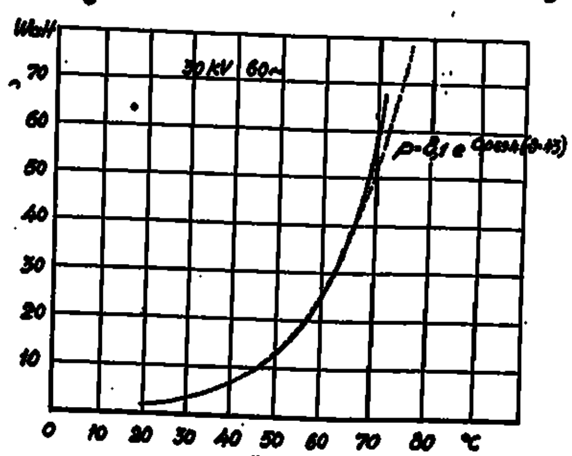


Fig. 4.

which thin plates can withstand $n > 2$. Here accordingly, with a constant external temperature, the breakdown voltage increases with the thickness of the test specimen.

If we only consider the fall in temperature between the electrodes and the surroundings *i.e.* if $\lambda = \infty$, the exact theory for relatively thick specimens, where $n = 2$, gives the same result as my elementary treatment; that is the breakdown

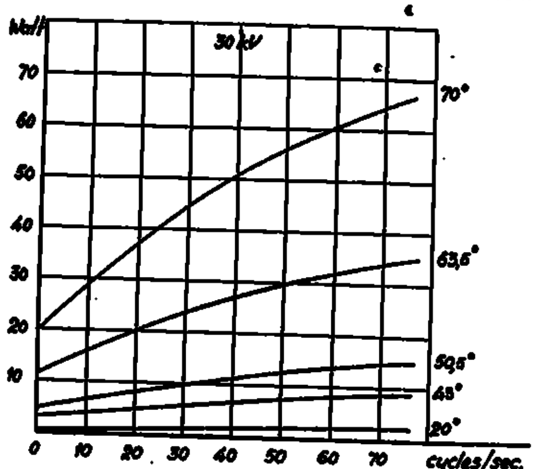


Fig. 5.

voltage increases as the square root of the plate thickness.

If we consider both the temperature drop in the specimen and also between the electrodes and the surroundings we also obtain an expression for the maximum breakdown voltage. This increases, as we should expect, for relatively thick plates with $n = 2$ much more slowly than as the square root of the thickness. I do not, however, propose to occupy time here by giving the mathematical expression for this.

It is sufficient to state that the theoretical conclusions agree very well with the experimental results.

As I pointed out before, the losses with high field strengths increase more quickly than as the square of the voltage. The reason for this is apparently that ionisation takes place in bubbles of gas imprisoned in the material. The modification of the law for brekdown with thin sheets of material is however not only due to this reason. It is clear that, when using thin plates of material, if the specimen is at all unhomogeneous this must greatly affect the result. Although when subjecting a condenser bushing to a test of long duration with large series resistance, no local breakdown can be observed, but the whole bushing or a greater part of it is warmed up, and if the temperature becomes sufficiently high, swollen up or carbonised, it is known that with thin test specimens local breakdown can occur, the material being otherwise unchanged. Clearly if a weak spot exists the losses will be concentrated at this point which is accordingly warmed up by a relatively large amount. Here also, a heat breakdown is possible, although the conditions are very un-

like those existing in the case of breakdown in quasi-homogeneous material.

Wagner investigated, in the article previously referred to,* just such breakdown which he conceived as a pure thermal proceeding analogous to the representation I gave earlier for quasi-homogeneous material. He considers a duct or canal in the specimen where the losses are concentrated, and investigates the requirements for thermal equilibrium. Here he considered the heat as only being conducted radially from the cylindrical canal, and obtained in this way the breakdown voltage proportional to the thickness of the layer. The general applicability of this result, however, differs so entirely from all experience that it must be abandoned. Wagner himself has certainly conducted a large number of tests, but on very thin specimens, and thus found his theory corroborated. The fact that the rule for certain material and for very thin specimens where the losses increase in proportion to a high power of the field strength, may be correct within certain limits is also demonstrated by the theory for quasi-homogeneous material explained above. It cannot, however, be even approximately general, and it is probable that Wagner's results, as suggested by Kármán and others, have their origin in the unhomogeneous wooden electrodes which were used by him for certain reasons in his investigations. The results obtained in this way thus do not depend on the characteristics of the actual material under test.

Dreyfus, Rogowski and others have later critised Wagner's exposition much more severely. Dreyfus has developed a very complete theory for "canal breakdown" for thin test pieces and has shown in this way that if attention is paid to heat conduction in both the axial and radial directions of the "canal" the result is that the breakdown voltage increases more slowly than the layer thickness which is in accordance with experience. To arrive by purely theoretical methods at any more definite results, causes us however, with "canal breakdown", to encounter difficulties as we depend on the "canal" dimensions which we cannot obtain exact knowledge of by any theoretical investigation since they depend on the unhomogeneous state of the material. Rogowski, who regards the new idea of breakdown, as a thermal phenomenon, as the most interesting advance in this direction since Townsend solved the problem of breakdown in gases, considers the action as a combination of thermal and electric phenomena.

For my part I have never gone as far as to state that in the case of solid bodies breakdown must under all conditions be regarded as a purely thermal phenomenon. A test specimen is unable to withstand easily high voltages even if the outgoing temperature is so low and the stress of such short duration that there is no time to reach a dangerous temperature. The atoms are held together by electrical stresses and sooner or later this power of retention must be lost, due to the action of the exterior field. It is certainly true that the retaining electrical forces between the atoms are apparently so great that they cannot be directly neutralised by any exterior field which it is possible to obtain in practice. But in most solid insulating material there exist spaces and pores which are filled with gas, whether air or vapours from the impregnating varnish, *etc.* Here impact ionisation can occur in the same manner as in gases and due to the imprisoned free electrons, the solid material can be broken up and a progressive breakdown commenced. Experiments carried out in the Asea laboratory on bakelite paper insulating material of some millimetres in thickness show that breakdown even with such high field strengths as 500 kV/cm requires a time approximately corresponding to the calculated time for thermal breakdown with quasi-homogeneous material so that it can be asumed with a large measure of probability that the breakdown is of a purely thermal nature up to and including field strengths of this order of magnitude.

To a great degree it may be said that with fibrous organic insulating material commonly used for high voltages, such as impregnating paper, cotton, *etc.* a pure heat breakdown occurs in so far as affects working at voltages ordinarily in use. A purely electrical breakdown can only be imagined in the case of normal voltages with such thin sheets of insulation as never occur in practice. Strains of short duration due to atmospheric discharges *etc.* may however act even in a purely electrical manner. In certain inorganic material such as mica, porcelain, glass *etc.* dielectric losses, even at temperatures between 50 and 100° are often so exceedingly small, that a breakdown entirely due to a thermal effect is only to be expected with very thick layers of insulation, or in the case of constructions which are well heat insulated. Here accordingly purely electrical or thermo-electric breakdown is relatively common.

I have discovered support for this idea in an article by Schumann in the Zeitschrift for Technische Physik, No. 9, 1925. In his article among other things measurements are given for glass lenses, the temperature immediately before breakdown having been measured by the alteration in the optical characteristics and it was there-

by established that no appreciable temperature increase existed.

In conclusion I must just touch on the fringe of a question which is closely connected with the nature of breakdown, the character of dielectric losses. If we wish to explain fully the purely physical nature of breakdown it is impossible to escape the solution of the problem of dielectric losses also. I shall here confine myself to referring to my above mentioned article in Teknisk Tidskrift in 1916. I endeavoured to show there that the dielectric losses are entirely conduction losses in an unhomogeneous dielectric. Possibly this is going too far. On the other hand it is indisputable that any fibrous material such as varnished paper preparations *etc.* and with temperatures where heat breakdown occurs, the dielectric losses, to an altogether overwhelming extent, are made up of just such ohmic losses. We obtain here the most perfect agreement between theory and experiment. Especially in the case of the material which is imperfectly dried we often obtain a maximum loss with about 30°. The losses begin once more to increase at about 50°. The maxima and minima in question are transferred at higher frequencies in the direction of higher temperature. The calculated curves show similar curious properties.

R. Liljeblad.

Bibliography:

Liljeblad: "Det elektriska fältet och de dielektriska förlusterna". Teknisk Tidskrift, Elektroteknik No. 8, 1916.

Liljeblad: "Om kondensatorgenomföringar". Teknisk Tidskrift, Elektroteknik No. 9, 1916.

Dreyfus: "Matematiska teorier för genomslaget hos fasta isolationsmaterial". Teknisk Tidskrift, Elektroteknik Nos. 3, 5, 10, 11, 1924, and "Mathematische Theorien für den Durchschlag fester Isoliermaterialien". SEV Bulletin 1924, pages 321 and 577.

Dreyfus: "Om kondensatorgenomföringar", Aseas Tidning, No. 3, 1924.

Dreyfus: "Uppfattningen om genomslagets natur hos fasta isolationsmaterial med särskild hänsyn till utvecklingen i Sverige", Aseas Tidning, Nos. 5—7, 1925.

Wagner: "The physical nature of the electrical breakdown of solid Dielectrics", Journal of the A.I.E.E., Dec. 1922.

Hayden and Steinmetz: "Insulation Failure — A Pyroelectric Effect", Electrical World, Oct. 1922.

Clark: "Dielectric Properties of Fibrous Insulation", Journal of the A.I.E.E., Jan. 1925.

Marbury and Ghait: "Dielectric Absorption in Fibrous Insulating Materials", The Electric Journal, 1925.

Rogowski: "Der Durchschlag fester Isolatoren", Archiv für Elektrotechnik, May 1924.

Kármán: "Ueber das thermisch-elektrische Gleichgewicht in festen Isolatoren", Archiv für Elektrotechnik, May 1924.

Rochow: "Ueber einige Fragen der elektrischen Festigkeitslehre", Archiv für Elektrotechnik, Febr. 1925.

Mündel: "Zum Durchschlag fester Isolatoren", Archiv für Elektrotechnik, Dec. 1925.

Günther—Schulze: "Ueber die elektrisch Festigkeit", "Lebende Bücher", published by von Dechert, Gruppe Elektrotechnik, Vol. I, 1924.

Hentschel: "Ionisierungserscheinigung im Kabeldielektrikum". Der Elektrische Betrieb, Nov. 1925.

Dieterle: "Die Durchschlagsspannung fester Isolierstoffe", E.T.Z., March 1925.

Klein: "Ermüdung von Hochspannungskabeln", E.T.Z., March 1923.

Schuman: "Ueber Versuche zur Natur des elektrischen Durchschlags", Zeitschrift für Technische Physik, No. 9, 1925.

Gahler: "Ueber den Zusammenhang von Strom und Spannung in festen Dielektrizis", Archiv für Elektrotechnik, Feb. 1925.

SOME IMPORTANT ELECTRICAL CONCEPTIONS POPULARLY TREATED.

The electrical characteristics which are considered most suitable for discussion in the present article have regard to electric motors, and are: losses and efficiency, heating and methods of cooling, and reactive power and cos φ.

The losses in electric machines (motors) are of two chief kinds: (1) mechanical, (2) electro-magnetic.

The mechanical losses consist of friction in bearings, commutators and sliprings, and windage due to rotation with which must be included losses due to any arrangements for cooling. Their magnitude is dependent on the speed of the machine, and in such a way that their connection is in general somewhere between direct and quadratic proportionality to the speed. Only in cases where the windage losses are very large can the proportionality be greater than the square. They are constant with constant speed and, practically speaking, independent of the load. The magnitude of the mechanical losses is usually from 1 to 2 % of the full output in the case of motors of small and medium size.

The electro-magnetic losses consist partly of *iron losses* and partly of *copper losses.* The former have their origin in the sheet from which the iron core (the armature of a D.C. machine and the stator of a three-phase motor) is made up. One variety of iron loss is called *hysteresis* loss and depends on the quality of the sheet used (alloy) being due to a certain sluggishness of the iron in changing its magnetisation, while another variety, *eddy-current loss,* depends partly on the quality of the sheet (the electrical conductivity) partly on the thickness. The lower the electrical conductivity and the thinner the sheet, the smaller is the loss. Iron losses change with the speed but at a constant speed are independent of the load. In their outward effect they accordingly resemble the mechanical losses and are usually included with these under the general designation *no load losses,* denoted by p_0 (watts or kilowatts). Copper and resistance losses manifest themselves in a wholly different way and depend on the resistance of the conductors and windings being always proportional to the square of the current flowing. As the current in that type of machine which we are chiefly considering, namely the three-phase induction motor, is approximately proportional to the load, it follows that the copper losses are proportional to the square of the load. They are usually denoted by p_{Cu} (W or kW). In fig. 1 the two chief varieties of losses, p_0 and p_{Cu} for a common induction motor (the speed of which is of course practically constant) are drawn in curves as a function of the load, and likewise the *derived efficiency curve.*

If we draw a tangent from the origin to the curve of total losses, the point of contact of the tangent denotes the load for which the efficiency is a maximum. And the tangent of its angle of inclination (tan α) is also the magnitude of the corresponding percentage loss. In this case the maximum efficiency occurs at about 5.5 kW and the percentage loss is accordingly $\frac{0.67}{5.5} \cdot 100 = 12.2\,\%$ and thus the maximum efficiency $\eta = 87.8\,\%$.

Electric motors, as is well known, become warm when running — sometimes more and sometimes less — and it is not without reason that we connect the degree to which heating takes place with the quality of the motor. A high temperature of course adversely affects the reliability and the length of life of the motor — and in particular as regards the insulating material used such as cotton, paper etc. The heating is of course caused by the losses which have just been referred to, and if the motor becomes hot (or too hot) this indicates that the losses are too high. This is actually the case but it may not always follow that on this account

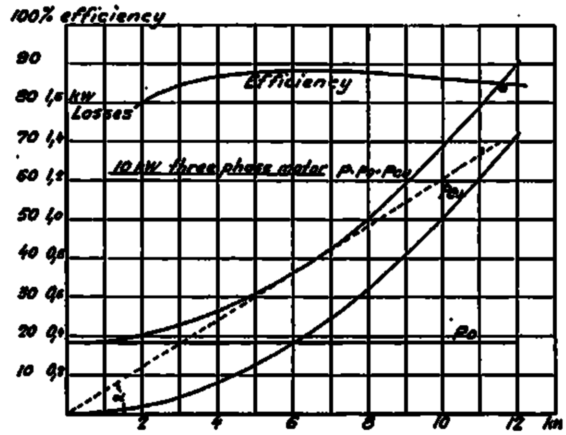
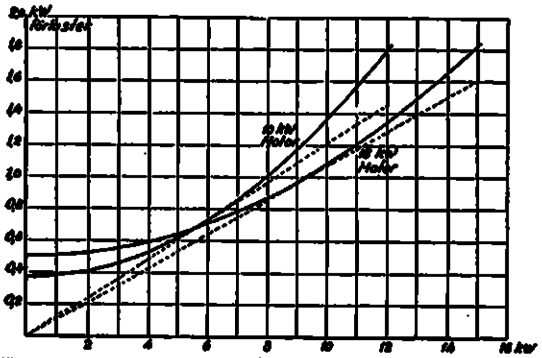


Fig. 1.

the motor is a bad one. Excessive heating can for example be due to the fact that the motor is overloaded or that the conditions as regards cooling are inadequate. It cannot be too strongly emphasized that insufficient ventilation always leads to overheating. But it should be noted that there is a limit to ventilation; it costs money in the same way as losses, and one should not go further than to ensure that the motor with adequate ventilation

and full (normal) load will not attain a temperature which would endanger reliability.

There is however another limit to cooling which does not depend on the necessary power expenditure. In certain industrial applications it is necessary to ensure that the inner parts of the motor are not exposed too much to the air which surrounds the machine; this both from the point of view of keeping the motor clean and



förluster = losses Fig. 2. Load

also with regard to fire risks. If the air surrounding the motor is laden with dust the motor should be ventilated by means of air brought from outside the factory, or the machine must be totally enclosed and no ventilation allowed for. In the former case the motor is of approximately normal size and costs only slightly more, although the necessary fans and duct work take up space, increase the capital charges, and absorb power. In the latter case the motor is much larger and more expensive and the losses* may possibly be higher.

We will now more closely examine this rather indefinite statement regarding increased losses. In fig. 2 the loss curves are drawn as a function of the load for a 10 and for a 15 kW motor and from these it is seen that the small motor has a better efficiency up to 5.5 kW while above that point the efficiency of the larger motor is higher. If the output which the motor is required to develop is 10 kW it will be seen accordingly that the larger motor has the lower loss and the higher efficiency. As in general motors are designed with copper losses which are twice as great at full load as the no-load losses the highest efficiency occurs at about 70 % of full load and as on the other hand the maximum efficiency is higher for large motors than for small ones it will easily be understood that the larger motor has better efficiency in the neighbourhood of the full load capacity of the smaller machine.

To return now to the question of cooling, it can accordingly be said that the large totally enclosed motor without cooling pipes has lower losses than the smaller totally enclosed motor with pipe ventilation for which in addition the larger losses are increased by the losses occurring in the fan. The larger machine certainly costs more than the smaller one, but the question to be considered is whether the increased price is greater than the increased cost entailed by the fan and cooling pipes, and it should also be borne in mind that the larger motor entails lower amortisation due to its greater reliability, longer time of amortisation, and higher value at the conclusion of the amortisation period.

We shall return to this question later on in conjunction with

The reactive power and cos φ.

In recent years a great deal has been said on the subject of cos φ, perhaps more than is really helpful. The reactive power which is the cause of low cos φ is certainly an evil, but evil must exist — otherwise it would be impossible to appreciate anything good — and the only thing to do is to keep the evil within reasonable limits, or even to turn it to good account.

The reactive power which an ordinary induction motor takes of necessity from the supply, is required partly for magnetising the iron core, and partly for the so-called magnetic leakage field. The former part of the reactive power appears even when the motor is running at no-load, the latter part arising as the load is applied. The former can, like no-load losses, (the active no-load power) be regarded as constant (with constant speed and voltage) over the whole load range while the latter are similar

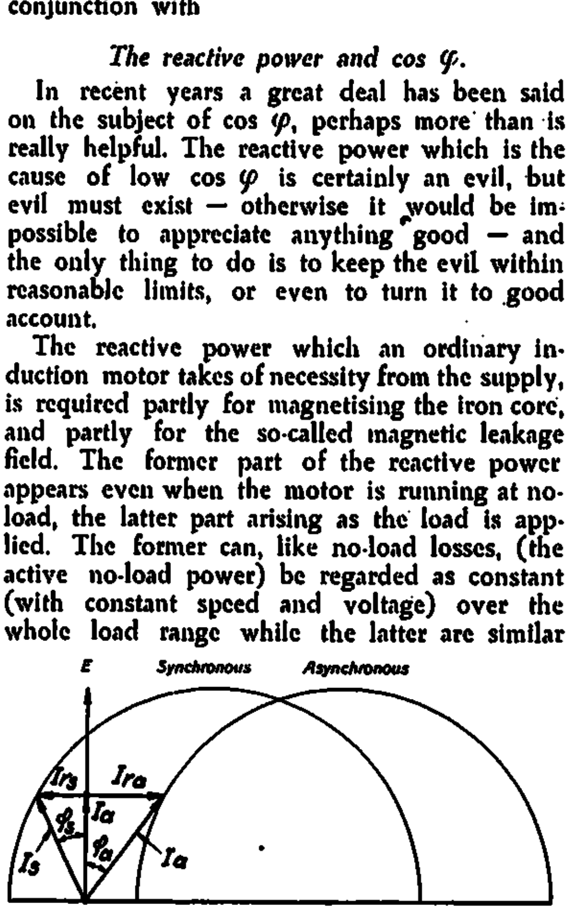


Fig. 3.

to the copper losses and thus increase as the square of the load. Since the reactive power (like the active) is represented by the product of voltage and current, and the voltage is seen to be constant, it follows that the reactive current, which the motor requires and uses, varies with different loads in the same way as the reactive power, and accordingly approximately as in fig. 1, if p_0 and p_{Cu} represent the constant and variable parts respectively of the reactive power or current, naturally with the

difference, that the relation between the two parts is in general otherwise, the variable part being relatively smaller.

From the simple Heyland diagram for a three-phase induction motor a number of important working characteristics can be obtained, such as cos φ at various loads, overload characteristics, etc.

Here we shall not deal further with the Heyland diagram, except, returning to the large totally enclosed motor without pipe ventilation, as a substitute for the smaller enclosed motor with pipe ventilation, previously mentioned, to establish the fact that by the choice of the larger motor we obtain a lower power factor (cos φ) than with the smaller motor.

We can however get round this disadvantage by ordering the larger motor for a higher voltage than that which will actually be used, by which means we certainly adjust the losses and efficiencies a little in accordance with fig. 2, but obtain a cos φ so altered that the larger motor is practically as good as the smaller in this respect.

In connection with this we would, however, say that the customer by careful selection of the voltage when placing his order, or the supplier by skilful design and construction can ensure that the larger, totally enclosed motor without pipe ventilation, will be better as regards efficiency and not worse as regards power factor than the enclosed pipe ventilated motor.

Lastly by the help of a diagram we shall show, how a synchronous or autosynchronous motor can improve the power factor or reduce the amount of reactive current and power when this is too great.

In fig. 3 diagrams for both classes of motor, synchronous and asynchronous, are drawn together. From these it will be seen that the reactive current of the former motor is negative as also is the phase displacement. It follows that the positive reactive current of the asynchronous motor is compensated to a greater or less extent by the synchronous motor and herein lies the value of the practice lately developed, and continually gaining ground, of displacing asynchronous motors on large installations by synchronous or autosynchronous motors in cases where working conditions allow the use of a motor running at synchronous speed.

It should be unnecessary to go further here into the question of the disadvantages arising from reactive current. We may, however, point out that the reactive energy is not an actual power, corresponding to a definite expenditure of water or steam, but that the reactive current is added to the active, giving an increased total current value which in turn increases the losses in generators, transformers and feeders, and so lowers the efficiency of the whole installation.

This addition is not, luckily, an arithmetic addition but a geometrical addition in the same way as two forces at right angles. This introduces the condition that a small phase displacement *i.e.* cos φ in the neighbourhood of 1 does not exercise any great effect. It is when we reach the point where $\varphi = 30$ to $40°$, *i.e.* when cos φ reaches 0.8 or is lower than this figure, that the disadvantages become of a serious nature.

A. Lindstrom.

THE FRONT PAGE.

The photograph on the front page shows one of two self-cooled transformers manufactured by Asea for the Sydsvenska Kraft A.-B. of Malmo, Sweden, each of 12,000 kVA, $\frac{56,500}{46,500}$/5,600 volts, 50 periods, provided with extra terminals for voltage regulation on load and designed for outdoor installation.

At the present time Asea also has under construction for the same firm 2 very similar transformers, one designed for 18,000 kVA, 47,000/52,000 volts and the other for 6,000 kVA, 56,500/5,600 volts and this order as a whole may be regarded as a good example of the capabilities of Asea as regards transformer construction.

The largest sizes in self-cooled transformers previously delivered by Asea were as follows:

1910	1,000 kVA
1915	1,500 kVA
1920	3,600 "
1925	12,000 "
1926	18,000 "

Sizes which in 1910 were looked upon as technically impossible do not now cause Asea any difficulty whatever. The main reason why such transformers can now be constructed of the self-cooled type is that use is made of powerful radiators which are joined to the transformer tanks and by which means sufficient cooling surface and effective cooling is obtained. As the radiators can easily be removed they are easy to maintain clean and free from oil sludge while at the same time transport does not give rise to any difficulty in spite of the fact that the transformers, as will be seen from the photograph, are of very large dimensions on account of their high output.

ELECTRIC SECTIONAL DRIVE OF PAPER MACHINES.

The problem of sectional drive for paper machines has been discussed in a number of publications during the last few years. The question has lately been of special interest to our engineers, as the first equipment for electric sectional drive has recently been set to work in Sweden. During the present year, Asea has installed the electrical equipment for a large paper machine for Holmens Bruk, Hallstavik. The excellent results obtained with this plant have led to the placing of orders with Asea for sectional drives in connection with further two machines for the same customer (one for a large new machine, and the other for the conversion of an existing machine), while interest in the system has also been evidenced in other places.*)

The running of a paper machine, it will be borne in mind, is characterised by the special requirement that the speed for which the machine is set, both as regards the absolute speed and the relative speeds between the various parts of the machine, must be kept constant within very close limits, while at the same time it must be possible to adjust this speed over a very wide range. When cleaning etc., it is also necessary to be able to inch the machine an exceedingly small distance at a time without difficulty.

Formerly, paper machines were, in general, driven by variable speed steam engines. The different parts of the paper machine were connected together by belt drives with conical pulleys and friction clutches so that correct variations in speed between the different sections could be arranged. During the last ten or twenty years, however, there has been a tendency to change over to electric drives, the paper machine simply being run by an electric motor instead of a steam engine and the same arrangements retained for transmission between the various sections. In the older plants, where a D.C. supply on the three-wire system was often available, use was made in a number of cases of ordinary D.C. motors with shunt regulation, or motors provided with two armature windings either in series or in parallel in combination with shunt regulation to obtain very wide speed range.

Since the three-phase supply has become general for all the larger industrial undertakings in most cases use has been made of the Ward-Leonard system. By a three-phase to D.C. motor-generator set, continuous current is generated, the voltage of which is varied by shunt regulation in the field of the D.C. generator. In this way a continuous speed range is obtained from the lowest possible speed up to full speed, for the main motor of the paper machine. This system has, from the point of view of regulation, considerable advantages over the older method with a D.C. motor operating from a D.C. supply at constant voltage.

Several advantages are gained by using electric drive instead of direct drive from a steam engine. The possibilities of maintaining the speed constant are greater than for the direct coupled engine, operation is improved and less attention is required. At the same time, naturally, the electric transmission involves certain losses. On this account it was urged in many quarters that a change to electric drive with a main motor was not justified. The supporters of the direct coupled steam engine have emphasised, among other things, the advantage of being able to use the exhaust steam direct for heating drying cylinders. This, however, really only applies to machines which work in general at the same speed. For machines which under different conditions operate at widely different speeds it should be noted that the amount of exhaust steam available only corresponds to the demand at a certain speed. Generally, perhaps, it may be said that as long as electrification was confined to driving by a main motor, retaining the old transmission gear, the value of electrification was, at any rate in some cases, very doubtful.

The question is on an entirely different plane if the electrification of a paper machine is effected by the use of electrical sectional drive. Here the full advantages of electric drive can be obtained.

First of all it should be noted that a saving of about 20 % in the power supply is obtained due to the elimination of the mechanical transmission.**)

The best of the systems now in use for speed regulation make possible, in addition, a much more definite adjustment of the relative speeds between the different parts of the machine. This means that the number of breakages occurring in the paper web are greatly reduced and production thereby much increased.

Production is also increased, and to a much greater extent, by the fact that the speed can be considerably raised. The belts in general make the speeds of necessity very low in the case of transmission drive. Seldom is it possible to obtain a higher speed than 250 m/minute. With sectional drive speeds up to about 350 m/minute can be obtained.

*) Since this article was written a further order for a similar equipment has been obtained.

**) For machines with a speed between 150 and 250 met./min.

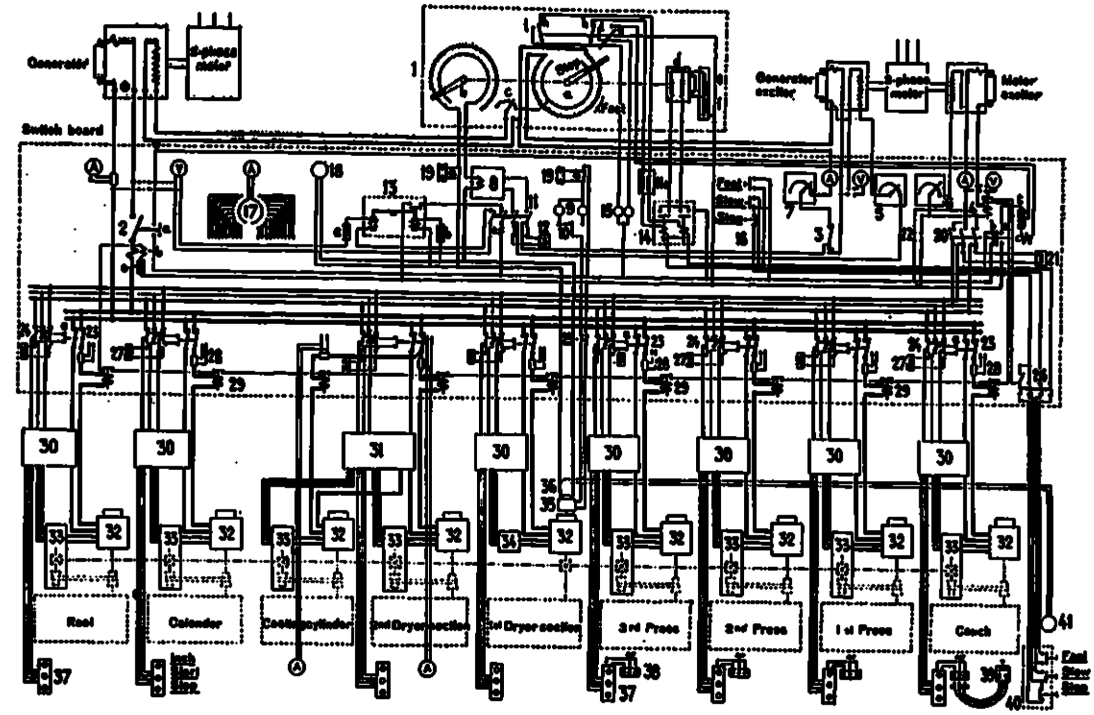


Fig. 1. Simplified diagram of electric equipment for paper machine with 9 motors.

1. Motor operated regulating apparatus.
   1a. Generator field resistance.
   1b. Adjustable resistance for pressure coil of regulator (8).
   1c. Adjusting resistance.
   1d. Operating motor.
   1e. Parallel resistance.
   1f. Series resistance.
   1g. Contact for closing (20). Only closes when the contact arm moves from the stop position in the direction "increase".
   1h. Limit switch.
   1i. Signalling contact.
2. Circuit breaker for generator.
   2a. Auxiliary contact for closing (20).
   2b. No-volt relay.
   2c. Series resistance for same.
3. Circuit breaker for generator exciter.
4. Overload relay, hand resetting, for motor exciter.
5. Field resistance, for generator exciter.
6. " " for motor exciter.
7. Adjusting resistance.
8. Speed regulator. (Voltage regulator).
9. Iron wire resistance.
10. Changeover switch for same.
11. Changeover switch for disconnecting (8).
    11a. Releasing relay.
12. Substitution resistance.
13. Differential relay. Releases 11 if tachometer dynamo voltage fails.
    13a. Series resistance for (13).
    13b. " " " (13).
14. Operating relay for (1d).
    14a. Series resistance for (14).
15. Signalling lamps.
16. Push buttons.
17. Ammeter changeover switch.
18. Speed indicator. (Voltmeter).
19. Plug contact for portable ammeter.
    19a. Short circuiting switch for (19).
20. Contactor with breaking contacts for the field excitation of the motors and for the starter operating current.
    20a. Retaining contact.
    20b. Operating contact. (After opening of (20), (1) returns to stop position).
    20c. Series resistance for (20).
21. Discharge resistance.
22. Fuse for operating circuit.
23. Disconnecting switches for the separate motors.
    23a. Auxiliary contact for breaking the operating current for the starters.
24. Disconnecting switches for motor fields and starting operating circuits.
25. Disconnecting switch for field winding of tachometer dynamo.
26. Switch for operating circuits.
27. Discharge resistances.
28. Ammeter shunts.
29. Overload relays with delayed action.
30. Starters.
31. Starter common to 2 motors.
32. Motors.
33. Shrinkage regulators.
34. Field resistance for master motor.
35. Tachometer dynamo.
36. Fuses for same
37. Push button boxes for the separate motors.
38. Plug contacts.
39. Portable push button for "inching".
40. Push button box for common speed regulation.
41. Speed indicator.

The windage set up by the large belt transmission also causes the paper to be unevenly dried, thus lowering the general quality, and often making it necessary to scrap a large part of the output. With sectional drive it has been found much more easy to obtain even drying of the paper.

Convenience in operation is also greatly increased. Starting and stopping of the different sections as well as alteration in the overall machine speed can be effected from push buttons mounted on the front of the paper machine. During examination of the machine, and especially during the frequent cleaning of the wire, control can be easily effected by means of a portable push button attached to a flexible lead and accessible from any suitable point. The machine in this way can be inched forward in suitably small amounts by the man carrying out the cleaning.

Lastly considerable space is saved due to the elimination of the transmission arrangements especially in the basement so that the building costs are much reduced.

If the costs incurred by electric sectional drive are compared with those when the drive is made with a main motor and transmission they are more likely to be lower in the case of sectional drive. The primary driving unit in the Leonard set is smaller in the case of sectional

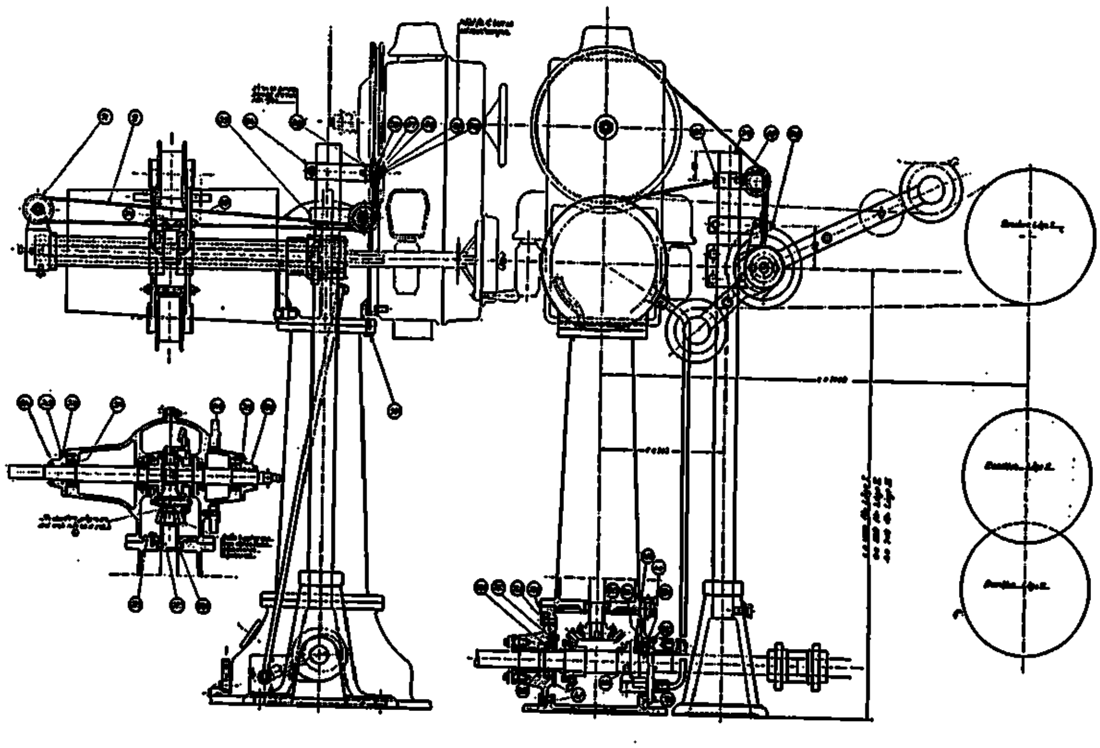


Fig. 2. Shrinkage regulator.

drive due to the saving in power by eliminating the transmission. The switchgear for this system is largely unaltered. Instead of the main motor with starting resistance etc., and transmission for the paper machine, separate motors are used with starters and speed regulating arrangements. Yet the increase in the price of the electrical equipment should not, in general, be greater than the saving effected on the transmission.

Under such conditions the equipment of any new large or medium sized paper machine with anything but electric sectional drive is hardly worth consideration. The advantages with sectional drive are in themselves so great that, in many cases, it pays to convert older transmission driven machines, and a number of such changes have already been carried out or are under consideration in various parts of the country.

When designing the drive of a paper machine on the sectional system we can reckon with a saving of about 20 % in the power required (in comparison with a machine with Leonard drive and a main motor). It is practically impossible to give any simple rule of general applicability, as even machines of approximately the same size give widely varying results.

The best course to pursue is undoubtedly to make use of experience already gathered from similar machines with transmission drive taking into account the saving mentioned above, due to elimination of the transmission. The speed for sectional driven machines, it is true, can be pushed higher than formerly, but we can approximately assume that the torque necessary increases with the fourth root of the speed and the power required accordingly somewhat more rapidly than the speed within the speed interval between that normally used with transmission driven machines and the highest obtainable with sectional drive.

Regarding the division of the power between the different parts of the paper machines there is, unfortunately, less experience available from transmission driven machines as in general no simple means were available for determining this power distribution. As a rough approximation we can say that the wire requires about 20 %, the wet presses about 25 %, the drying rolls about 35 % and the calender and reeling apparatus about 20 % of the total power. Large variations are, however, found in different machines. It should also be remembered that large differences occur in the power required for driving different arrangements of wet end, depending on the location and type of the suction boxes.*)

Finally, two systems for electric sectional drive are conceivable. The first and most important

*) For calculating power requirements see further W. Stiel, "Elektrische Papiermaschinen Antriebe".

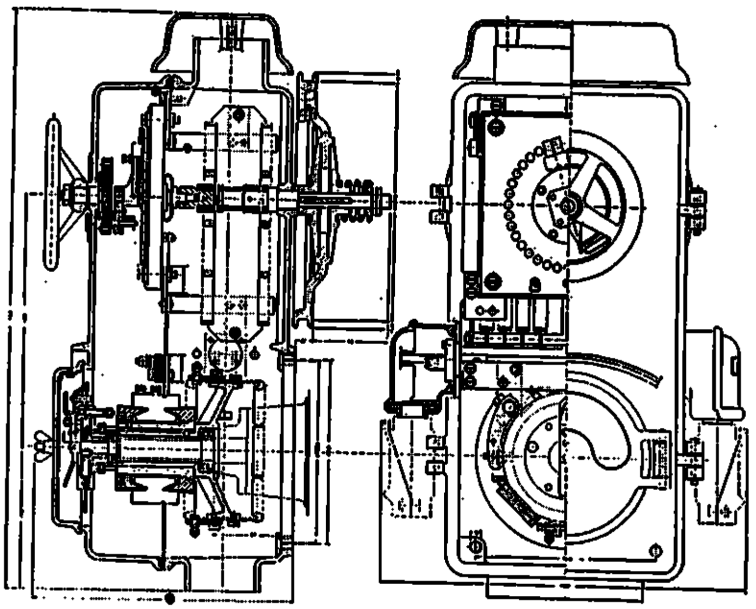


Fig. 3. Rheostat box of shrinkage regulator.

The first experiments in Germany and America which were carried out about 1909 were failures because this exact requirement regarding relative speed was not appreciated. An attempt was simply made to supply machines running at speeds as constant as possible, and to this end provided with an exceedingly large number of studs on their shunt resistances so that speed could be adjusted by hand very closely. It was, however, found in practice to be quite hopeless to regulate the different motors to a certain constant speed. The unavoidable departures from this speed were cumulative and at last a higher strain occurred than the paper was able to withstand without breaking. What we have to obtain is thus a regulation on the same relative angle between a certain radius in the different rollers, so that, for example, a departure from the correct speed during a given instant will be compensated in the next instant, not only by the regulator restoring the speed, but also first giving a small overalteration of the speed in the opposite direction.

is the Leonard system, *i.e.* the same system as used for driving with a main motor but employing separate D.C. machines coupled to the different parts of the paper machine. The other is the direct A.C. drive, using commutator motors with speed regulation by brush shifting. In what follows we shall chiefly deal with the first mentioned system.

In maintaining the speed constant on a section motor no great difficulties are experienced (see fig. 1). It is done in the same way as with the Leonard system, using a main motor. The section motor is furnished with a tachometer dynamo, the current from which traverses the coil of an automatic regulator, the contacts of which regulate the amount of resistance in the field of the exciter of the generator. Equilibrium obtains only when the voltage of the tachometer dynamo, and thus the speed of the driving motor, is equal to that for which the machine is adjusted. To enable the regulator to operate for different speeds it will be seen from the diagram that its coil is connected in series with a rheostat which is operated at the same time as the field resistance of the generator. Thus the regulator always has the same voltage applied to its coil at all speeds.

Although it is easy to obtain a constant speed for the first motor or for one motor it has been a very much more difficult problem to get correct relative speeds between the different parts of the paper machine. The necessary exactness is here of a very high order and departures from the predetermined speeds must not be more than a small fraction of 1 %.

This problem would naturally be easy to solve if it were not for the shrinkage in the paper web. It would be a simple matter to synchronise the different machines, for example by furnishing them with sliprings as on a rotary converter, and paralleling the motors on the A.C. side. The shrinkage in the web of paper, from the wire to the end of the drying rolls, reaches however several per cent and also varies for different classes of paper. It is, therefore, necessary to be able to adjust the different motors for certain speed differences. A conceivable solution would naturally be to make use of the above mentioned synchronisation but to allow each motor to drive the respective part of the paper machine through an adjustable belt running on conical pulleys. In this way, however, many of the advantages occuring from sectional drive disappear, and losses again occur in the transmission.

The General Electric Company, however, as late as 1919 introduced a system closely resembling the above in principle. For each D.C. motor there is a small synchronous motor having an output of about 20 % of the output of the D.C. machine and which is connected to the shaft of the D.C. motor with a belt drive on conical pulleys. All the synchronous motors

are connected in parallel. If now one part of the paper machine strives to alter speed; this is made impossible since all the synchronous motors run in parallel. It follows that the synchronous motor for the part in question takes over a proportion of the driving power which was before supplied by the D.C. motor connected to it. (The assumption is naturally made that the alteration in power is not so great that the synchronous motor will be so overloaded as to drop out of step.) In this way we have at any rate secured an arrangement by which the belt drive does not transmit more than a part of the power. By hand regulation in the shunt field of the D.C. motor it is clear also that the synchronous motor and belt drive can afterwards be unloaded, the D.C. motor being made to take over the whole output.

It need hardly be pointed out that even this system is by no means perfect. Belt drives for considerable powers still remain while the synchronous motors increase the total cost of the installation materially. In addition, hand regulation must still be used to a great extent if the synchronous motors and belt drives are not to be overloaded under certain conditions.

It is clear that a solution correct in principle must ensure that the D.C. motors have their correct speeds maintained directly. Such an idea was put forward for the first time in 1912 by G. Stjernberg, M.I.E.E., now head of the Sales Department in Asea, and at that time manager of the English branch of the AEG. The AEG had delivered an equipment for sectional drive of a paper machine to an English firm, The Wall Paper Manufacturing Co., although the machines were not furnished with any direct regulating arrangements but only finely divided field rheostats and partially compounded motors. The proposal of Stjernberg led, however, to the provision of regulating arrangements for the most sensitive parts of the machine. (A patent for this arrangement was later applied for and granted in 1913 by the AEG but was not kept in force probably due to the outbreak of the War, when most of the staff who had been concerned with the regulating arrangement in question left the firm.) The installation of the

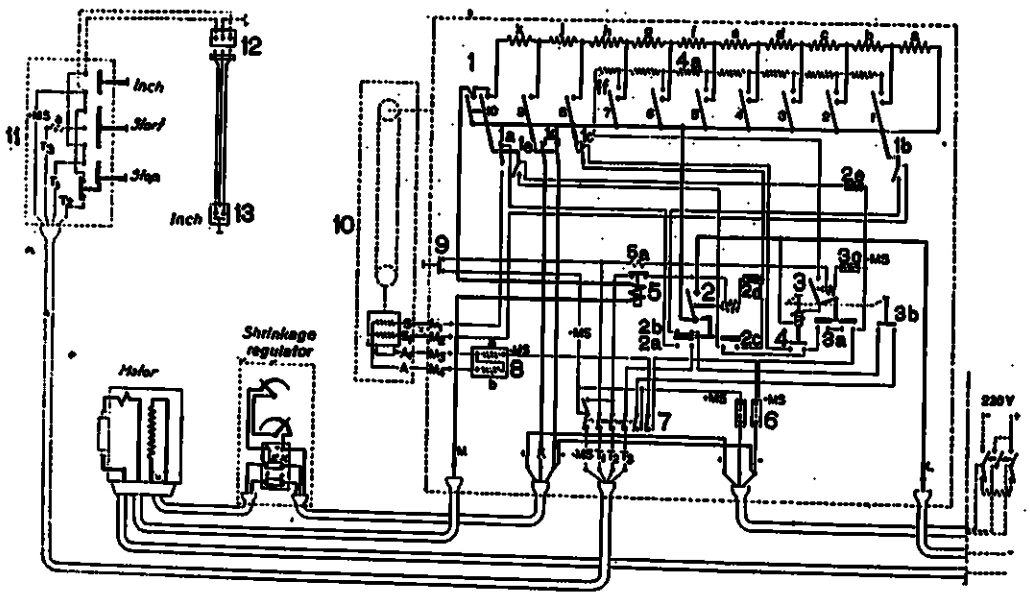


Fig. 4. Diagram for motor operated starter of sectional driving motor.

1. Starter.
   1a and 1b. Limit switches for operating motor.
   1c. Interlocking contact.
   1d. Contact for short circuiting shrinkage regulator during starting.
   1e. Retaining contact. Short circuits the closing contact of the auxiliary relay when the starter is all out.
   1f. Voltage contacts.
2. Main contactor.
   2a and 2b. Auxiliary contacts for operating the motor 10.
   2c. Holding in contact.
   2d. Series resistance.
   2e. Auxiliary contact.
3. Intermediate relay.
   3a. Closing contact for (2).
   3b. Auxiliary contact with delayed action for running the operating motor in the direction "off".
   3c. Series resistance.
4. Voltage relay. To enable the relay to close the contact, (3) must be closed and the current in the coil be less than a predetermined value.
   4a. Voltage resistance (= series resistance for 4).
5. Instantaneous overload relay.
   5a. Locking magnet for same.
6. Fuse for operating circuit.
7. Disconnecting switch for operating circuits. The control leads can, if necessary, be disconnected during running for examination without interrupting the working.
8. 8a. Series resistance for operating motor.
   8b. Parallel resistance for operating motor.
9. Push button. Used only when operating by hand.
10. Starter operating mechanism.
11. Push button box. The stop button remains depressed and must be drawn out again before a new start can be made.
    11a. Signalling device. Shows red when the operating motor is running in the direction "on", otherwise white.
12. Plug contact.
13. Portable push button.

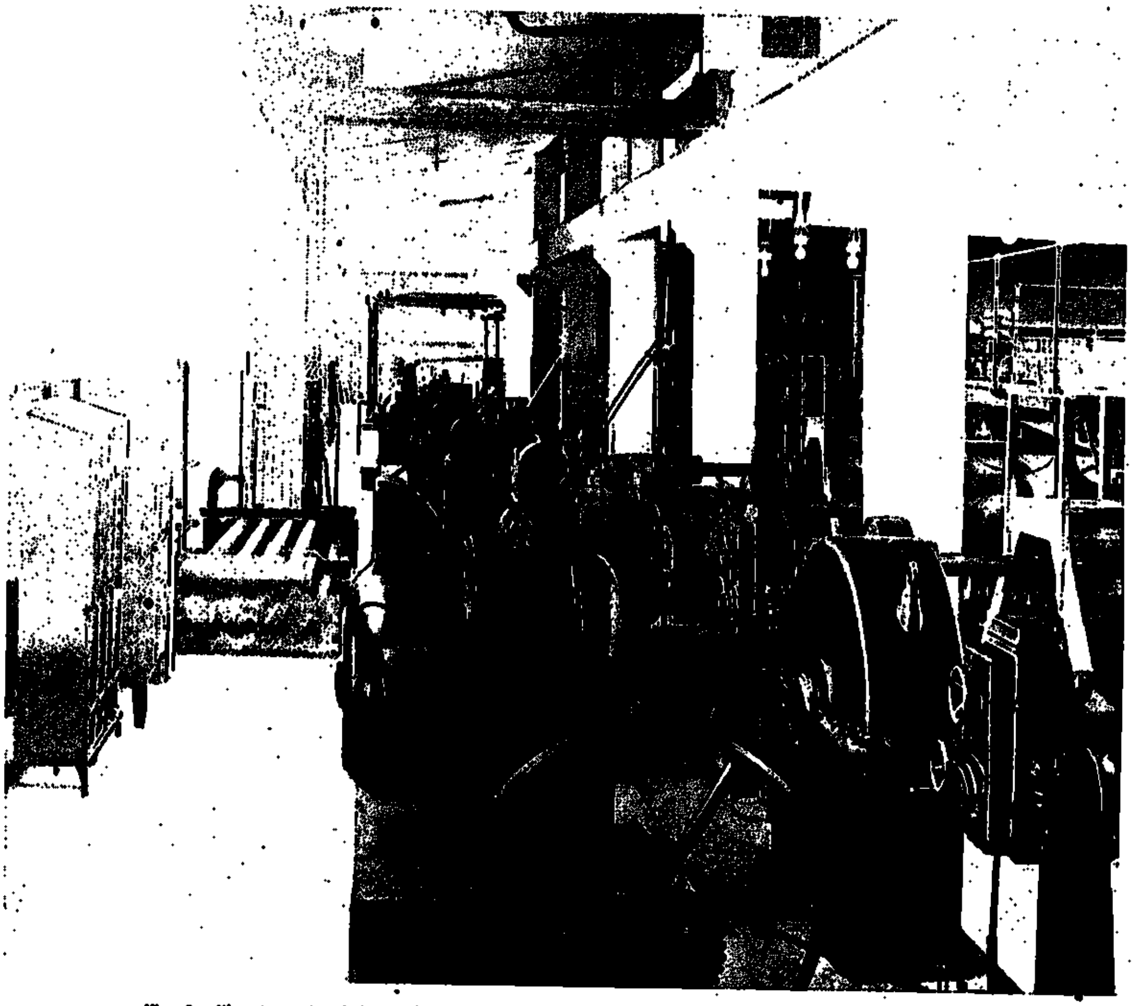


Fig. 5. Electric sectional drive of paper machine at Holmens Bruks Fabriks A.-B., Hallstavik, Sweden.

Wall Paper Manufacturing Co. was demonstrated in England to a number of interested engineers and paper manufacturers and aroused considerable attention. In 1914 the Harland Engineering Co. applied for a patent for the same arrangement and, thanks to the situation in England at the time and the imperfect circulation of information, they succeeded in their application.

Not until after the War were equipments for paper machines with electric sectional drive taken up seriously in America and England, while in Europe generally interest has only just been awakened.

The arrangement with the system referred to is in principle that of placing between the leading motor, *i.e.* the driving motor to which the tachometer dynamo for maintaining the absolute speed is attached, and the remaining motors, differential gears comprising three elements. The first element, the housing, is driven from the regulating shaft driven from the leading motor, the second element is driven by a belt running on conical pulleys from the respective motor shafts (or gear shafts), and the third element is connected to the shunt rheostat of the respective motors. If the speeds of the three elements at the same time are called n_1, n_2 and n_3 we get the equation

$$n_2 - n_3 = 2\ n_1.$$

The operating spindle for the shunt resistance can, evidently, not possibly spin round. Even a small movement amounting to a fraction of a turn alters the motor speed considerably and immediately. We thus obtain

$$n_3 = 0, \text{ and } n_2 = 2\ n_1.$$

The two first elements of the differential gear must accordingly work synchronously. Even after any length of time it would be impossible for them to become more than a fraction of a turn out of phase, as thereby the speed of the motor would be considerably altered. (As the

formula shows, one turn of the second element corresponds uniformly with two turns of the first.) The conical belt drive makes it possible, however, to vary the speed somewhat between the various parts of the paper machine in a manner corresponding to the shrinkage in the paper. The motor speed adjusts itself so that the equation $n_2 = 2\ n_1$ is true for the differential gear. It should, however, be noted that this belt drive does not transmit any considerable amount of power. It has only to deal with the friction losses in the differential gear.

The design of regulating apparatus produced by Asea, the so-called shrinkage regulator, is shown in figs 2, 3 and 6. From the leading driving motor a regulating shaft runs the whole length of the machine, passing through the bases of all the shrinkage regulators. From the regulating shaft the rotation is transmitted through bevel gears to vertical shafts in the bases of the regulators connected to the housings of the respective differential gears. The conical pulley will be seen in the illustration. The losses in the differential gear only amount to from 5 to 10 watts, so that the power to be transmitted through the belt is exceedingly small. Theoretically, there is always a certain amount of slip in a belt drive when any power at all is transmitted. The tight side of the belt runs on to the pulley somewhat thinner than the slack side and this difference is partly maintained as the belt passes over the pulleys. As, however, the same weight of belting must pass each point of the drive in a unit time it is clear that the speed of the pulley faces must be somewhat different and this difference changes with the load. The diameter of the belt pulleys has, however, been selected so large that the peripheral stress is sufficiently small to enable us entirely to neglect the slip due to the belt stretch for the small power variations of 5 to 10 watts, which occur depending upon whether the losses in the differential gear are supplied from the regulating shaft or from the motor shaft. With a common belt drive, transmitting a real amount of power, it is in general not possible to prevent the occurrence of an additional true sliding of the belt over the entire pulley in certain cases. With the belts in question such slip would not occur unless the greatest power variations actually occurring were to be exceeded 10 to 20 times. The factor of safety against the slip being too great is accordingly fully adequate.

It should, perhaps, be noted that it is the large slip which gives rise to the difficulties as regards speed regulation in the transmission drives which have so far been used.

In order to obtain as small steps as possible for the shunt rheostats of the motors, which has been found desirable to prevent hunting, *etc.* Asea has divided the resistance into two parts. This will be seen from figs. 3 and 4. The main portion of the resistance, or approximately 75 %, can be set by hand, and is automatically regulated at the same time as the belt is shifted. The belt is shifted whenever an alteration in motor speed is desired and at the same time a rough setting of the resistance can be obtained. The actual automatic part of the resistance is the smaller remaining section of about 25 %*). The shaft from the differential gear is connected to a small commutator between the segments of which the last resistance is coupled. The brushes are fixed. The differential gear thus functions in such a way that the commutator with the resistance appertaining to it turns through a small angle when a speed alteration occurs and thus corrects the incorrectness in speed. Normally the commutator makes small and hardly perceptible movements, the brushes being in turn upon one or both of two adjacent segments. As $n_2 - n_3 = 2\ n_1$ = constant, it follows that if $n_3 = 0$, *i.e.* if the commutator is stationary, n_2 is absolutely constant. If the collector makes a movement through a small angle φ_3 the cor-

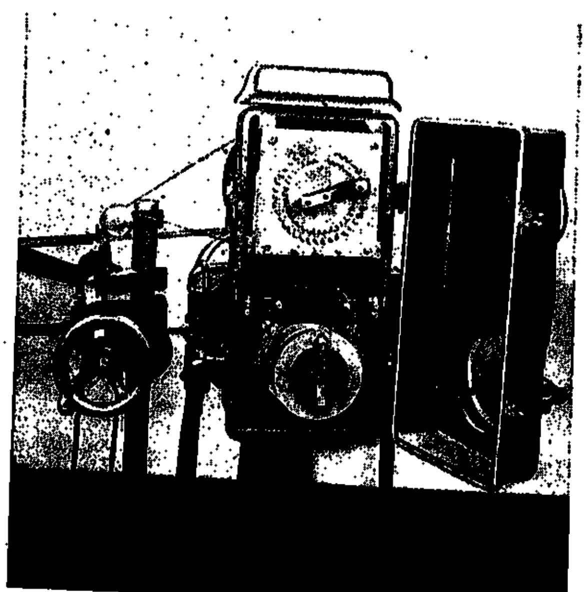


Fig. 6. Shrinkage regulator.

responding cylinder in the paper machine is displaced by a corresponding angle φ_2 in relation to the leading driving motor (on the assumption that there is no gearing between the regulator and the corresponding cylinder in the paper machine). It is thus of importance

*) Arrangement patented by Asea.

to make the construction such that the motor reacts to the least possible displacement of the commutator in the shrinkage regulator. The commutator is connected with the differential gear through a friction clutch which can slip for a long time without excessive heating. When the machine is started, which is most suitably done section by section, or when any section of the machine is stopped, the shaft from the differential gear to the rheostat rotates, and as the movement of the commutator is limited and amounts only to something less than half a turn the apparatus would be smashed without this friction coupling.

It is desirable that the motors should be compounded to give as far as possible constant speed between no-load and full load. When starting the machine a web of paper is first passed through the whole machine and this web is increased in width gradually until the full width of the machine is reached. When the suction boxes at the wet end become fully covered there is a sudden increase in the power absorbed. If this increase, apart from the regulating arrangement, gives rise to an inconsiderable speed variation the work of the regulating apparatus is simplified, the momentary speed changes are less, and the chances of breaking the paper are reduced.

It is clear that the motors can suitably be supplied as geared motors of the modern type or coupled to the paper machine through up-to-date precision gears.

Regarding the arrangements of the system further particulars can be gathered from figs. 1 and 4. The last figure shows the arrangement for starting. Starting is most suitable effected by push buttons from the front of the machine. In this case, a motor operated starter is used.

When designing the resistance it must be remembered that approximately $2^1/_2$ times normal current may be required for starting. This occurs in general at a relatively low voltage corresponding to about half normal machine speed. It is, however, necessary that the resistance should be designed so that starting can also be effected at full voltage. If, for example, the paper web should break in the drying section it must be possible to disconnect this section to enable the broken part to be removed and a new start made without having to alter the quantity of stuff supplied to the wire. The wet end must, accordingly be kept running. This condition makes it necessary for a large amount of care to be taken in designing the resistance. With a normal start with relatively low voltage a large part of the resistance must be short circuited before the paper machine gets away. If, however, the machine is started with full voltage with the resistance short circuited, a risk is run of the motor's either flashing over or burning out. Under such conditions we may obtain more than 5 times normal current. As the diagram in fig. 4 shows a safeguard against such incorrect operation is obtained by a type of interlock which makes it impossible to close the main circuit breaker if a suitable proportion of the resistance corresponding to the voltage is not in circuit*).

There are also other arrangements for electrical sectional drive with speed regulation by means of differential gears. The Westinghouse Co. have brought out such an electrical system where the differential gear is composed of a small three-phase motor. If the rotor of this machine and also the stator is supplied with current of the same frequency the rotor naturally remains stationary. If there is a discrepancy between the frequencies the rotor rotates at a speed corresponding to the difference between the speeds of the rotating fields in the rotor and stator. The Westinghouse Co. have since modified their system. Other firms have also used systems for electrical speed regulation. All these electrical systems are, however, more complicated than the system employing simple mechanical differential gears. They are all likely to have originated as attempts to get round the patents on the mechanical arrangement, in such quarters that have been ill informed as to the historical developments of the mechanical system and the consequent weakness of the Harland patent regarding novelty.

As we stated at the commencement, the only possible rival to the sectional drive system with D.C. motors is the A.C. drive with variable speed commutator motors by which the primary unit of the Leonard system can be dispensed with. Such installations have already been designed. The only motor which can be considered suitable for this arrangement is the Schrage motor constructed by Asea. This machine has shunt characteristics and the speed can be regulated in the ratio of 1 to 3 by brush displacement. By using a series resistance the speed can be further reduced but the machine naturally assumes a series characteristic if this is done.

The arrangement is otherwise similar in character to the D.C. system. Instead of the shrinkage regulator operating on the shunt resistance of the respective D.C. motors it works the brush shifting devices of the three-phase motors.

Occasionally one hears it objected that the direct use of a three-phase supply introduces the disadvantage that the absolute speed varies with the frequency of the supply. This, how-

*) Patent applied for by Asea.

ever, is not the case any more than it is with the D.C. system. The absolute speed of the leading driving motor can easily be kept by means of a regulator. For example, a mechanical centrifugal governor can be used for this purpose. It is also possible to use a tachometer generator, electrical regulator and operating motor for adjusting the brush rockers of the leading motor. Other means of similar character might also be used. There is, accordingly, no doubt that the system employing commutator motors is technically quite satisfactory. The question whether or not it will be of economic value must be investigated in each case, as the saving due to the elimination of the primary unit may be outweighed by the more expensive motors.

Figs. 5 and 6 are illustrations of the plant delivered by Asea to Hallstavik, Sweden. The paper machine in question has a width of 5.15 metres and working is arranged for a maximum speed of 325 metres per minute. The number of motors is 9.

Vesteras, Sweden, 1926. Vestmanlands Allehanda Printing Co.

ASEA-JOURNAL

ASEA

VOL. IV

1927

PUBLISHED BY

ALLMANNA SVENSKA ELEKTRISKA A.B.
VESTERÅS — SWEDEN

SWEDISH GENERAL ELECTRIC LTD
5, CHANCERY LANE — LONDON

INDEX

A S
E A

ASEA-JOURNAL

ALLMANNA SVENSKA
ELEKTRISKA A.B.
VESTERÅS — SWEDEN

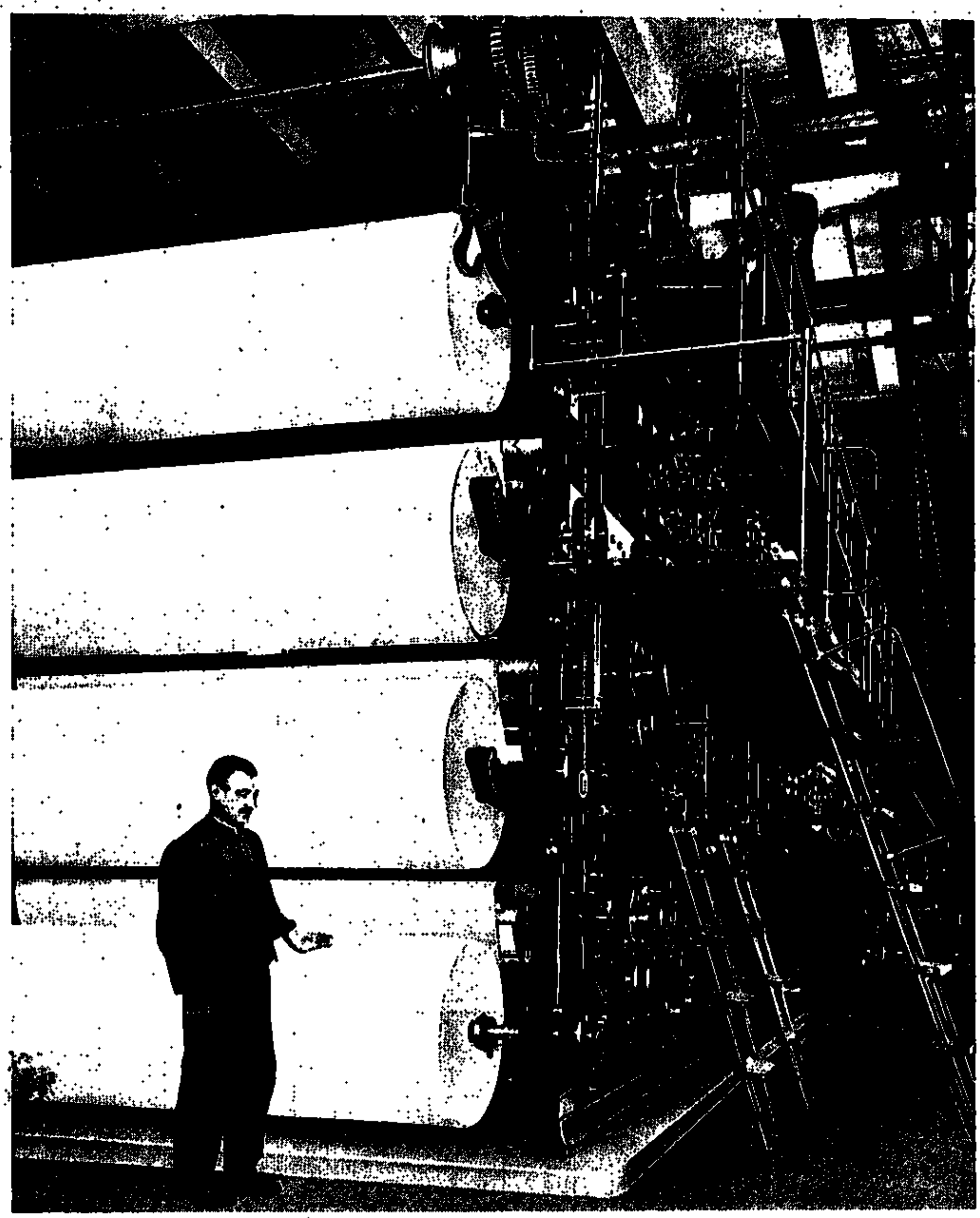
SWEDISH GENERAL
ELECTRIC LTD
5. CHANCERY LANE—LONDON

MONTHLY REVIEW

VOL. IV
1927

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesterås, Sweden.
Permission is given to reprint articles or extracts from this journal,
on condition that the name — Asea-Journal — is clearly stated.

JAN.-FEBR.
Nos. 1-2



Three colour printing press driven by 100 h.p. Asea motor. »Dagens Nyheter», Stockholm, Sweden.

ELECTRICAL EQUIPMENT OF PRINTING MACHINERY.

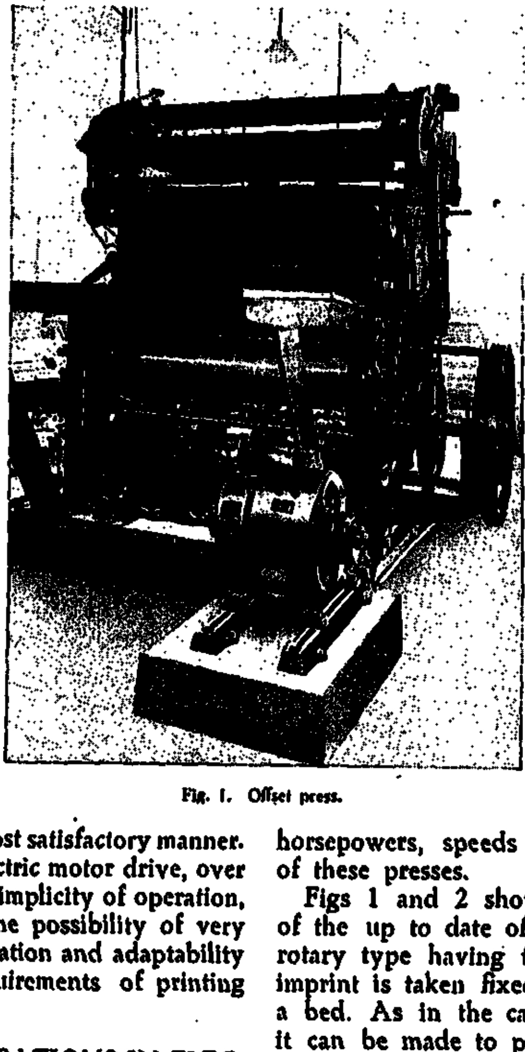


Fig. 1. Offset press.

During the last ten years the whole science of printing has undergone very rapid development. A changeover from uneconomical methods of working with small slow running machines to large fast running machine units and better methods of printing has been going on for a much longer period. Development in this direction has reached a height which can be gauged from the mammoth issues of modern newspapers, and the tasteful design of the latest books and journals with their artistic illustrations.

One cause of this quick development which cannot be overlocked is the electrical method of driving, which has solved the power question for printing machinery in a most satisfactory manner. The advantages of the electric motor drive, over and above compactness, simplicity of operation, cleanliness, *etc.*, include the possibility of very wide and even speed regulation and adaptability to meet the special requirements of printing technology.

I. GENERAL CONSIDERATIONS IN ELECTRICAL DRIVE OF PRINTING PRESSES.

Different Types of Printing Presses.

The most important machines in printing are the presses. For starting and regulating them special apparatus must be used. Auxiliary machines such as boring boxes, mangles, planing and type setting machines *etc.*, can, however, in general be furnished with electrical equipment of ordinary standard pattern. Presses, as regards principle, can be roughly divided into three classes, namely, flat bed presses, offset presses, and rotary presses. The principle point about flat bed presses is the arrangement of the type on a flat bed, which by means of a horizontal reciprocating motion comes into surface contact with the sheet of paper to be printed. The sheets are placed into position one at a time, either by hand or automatically, and are rolled round a cylinder (the impression cylinder) under which the type runs. For every forward and backward movement one side of the sheet is printed so that it must pass twice through the press before printing is completed unless the machine is of the "perfector" type which prints both sides in one operation and is really equivalent to two ordinary presses since it possesses two cylinders and a bed upon which two sets of type are fixed. The table below gives an idea of the power requirements, suitable horsepowers, speeds and regulation for some of these presses.

Figs 1 and 2 show the general appearance of the up to date offset press which is of the rotary type having the matter from which an imprint is taken fixed to a cylinder instead of a bed. As in the case of the flat bed presses it can be made to print both sides of a sheet in one operation but in as much as the sheet receives its imprint from a rubber blanket and not from the prepared type plates direct as in the case of the first class of presses the work it produces is of an entirely different nature. Flat bed presses are chiefly used for the better class journals, illustrations, books, forms, *etc.*,

Table I.

Appr. weight of press (kg)	Size	Max. copies per hour	Output for		Motor		Regulation	
			Starting	Max. r.p.m.	h.p.	normal r.p.m.	Series	Shunt
2000	510×820	1600	3.0 h.p.	2.3	3	520	33 1/3 %	50 %
4000	550×900	1500	5.0 »	4.0	4	865	45 %	50 %
5000	720×1100	1400	5.5 »	4.7	5	500	33 1/3 %	33 1/3 %
5000	720×1100	1400	6.2 »	5.1	6	560	33 1/3 %	33 1/3 %
9000	1200×800	1100	8.2 »	7.0	7	600	33 1/3 %	50 %
10000	1000×1400	1000	10.0 »	7.8	10	510	33 1/3 %	33 1/3 %

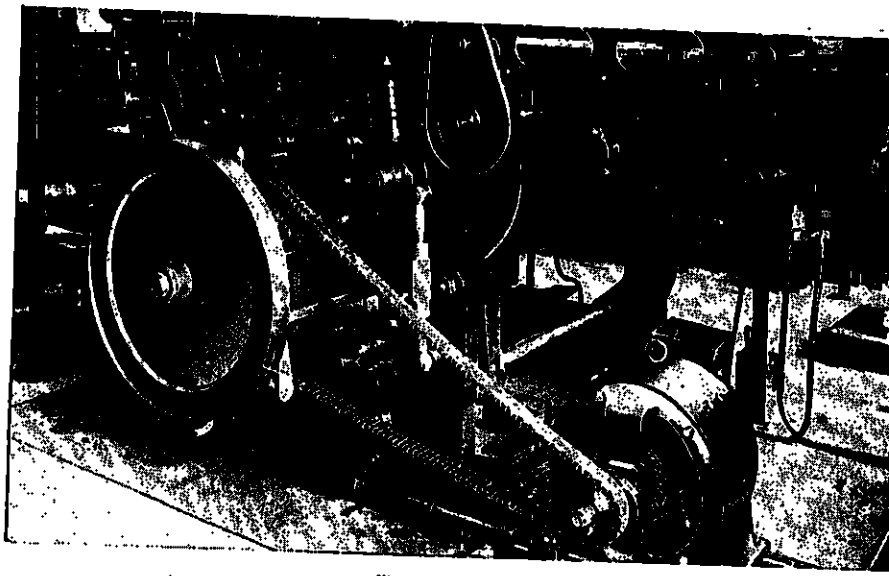


Fig. 2. Offset press.

whilst the major use for offset presses is for colour posters, letterheads, tin boxes and the like.

In rotary presses, the most known of which is the letter press type, although there are others such as photogravure embodying a special process, printing is effected by passing a web of paper between two cylinders, one of which is called the impresion cylinder and the other the plate cylinder. It is on the latter that specially prepared cylindrical type plates are fixed. The paper is unwound from large reels and is first printed on one side by a first pair of cylinders and then on the other by a second pair. These presses are chiefly used when it is necessary to obtain large numbers of copies, as for instance with newspapers, periodicals, *etc.* According to the size of the paper, 8, 10, or more pages are printed at the same time. The paper web is cut and the paper folded so that it comes out in finished condition. These presses are made in all sizes, and are classed according to the number of paper reels (or printing units or decks) which can be brought into simultaneous use as a maximum. In the case of large presses it is usual to build them in two sections with the folding mechanism of each adjacent each other in the centre and the paper reels at the two ends. Such a double machine can then be run either half at a time or both halves together, and is called a twin or double ended press. Such combinations can be developed to include three, four, or more presses. Fig. 3 shows a double ended press of large size. The size of the motor is in general determined by the press manufacturers but the horsepower given often varies considerably with similar sizes of press, and with conditions and different classes of work. Experience shows that the most satisfactory drive is obtained with machines of ample power. In table II is shown a collection of press data, speeds and motor sizes for some rotary presses, the motors of which under all working conditions have been found to meet all requirements.

The presses take in general considerably more power when they are new. When the gears and bearings are run in, the friction decreases considerably (as much as 30 %). Even under normal working conditions the power required may vary considerably. Cold bearings increase the necessary starting torque, while the quality of lubricating oil, impression between cylinders, *etc.*, react considerably upon the power requirements. The torque required for starting is from 2 to 3 times as great as that required when the press is brought up to a fair speed. At no load, *i.e.*, without paper and type plates, only

Table II.

No.	Type	Breadth of paper (m)	No. of rolls of paper	Maximum no papers printed per hour	Speed of printing rollers			Main motor	Auxiliary motor	Normal speed r.p.m.	
					Max.	Creeping	Adjusting			Main motor	Auxiliary motor
1	Single	0.75	3	12000	200	10	20/1	1 each 36 h.p.	—	420	—
2	»	1.50	2	10000	167	10	16.7/1	1 » 40 »	—	375	—
3	»	1.20	4	9000	150	8	18.7/1	1 » 40 »	—	420	—
4	Double	0.75	2×2=4	30000	250	5	50/1	2 » 30 »	2 each 3 h.p.	450	1400
5	»	1.30	2×2=4	24000	200	8	25/1	2 » 36 »	2 » 3 »	970	1400
6	»	0.90	2×2=4	26000	217	6	36/1	2 » 30 »	2 » 5 »	450	1400
7	»	0.75	2×2=4	24000	200	5	40/1	2 » 24 »	2 » 3 »	850	1400

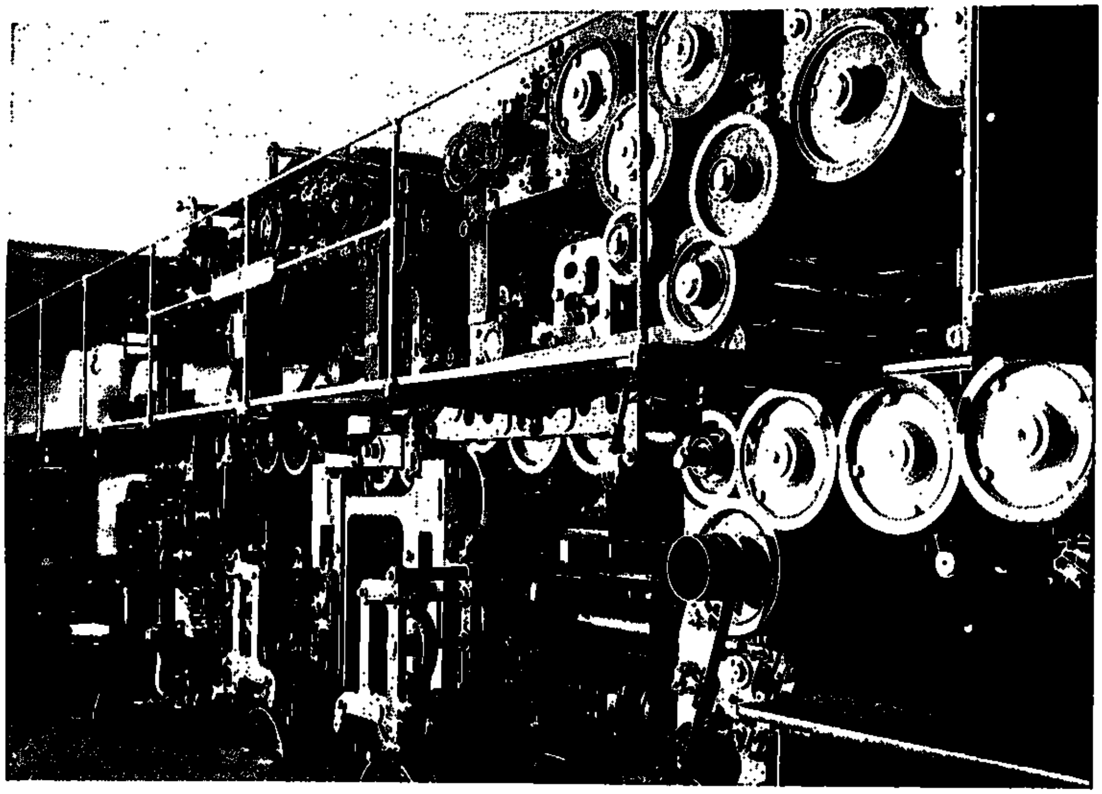


Fig. 3. Double rotary press.

about one half the torque is required as when the press is in full working order.

To give an idea of the variations in power, torque, and length of run which occur during ordinary printing, a series of measurements have been taken and are given below (see tables III and IV).

During a printing process lasting six hours the press was started up to the running position (1) approximately 200 times (for fixing the cylindrical type plates and threading through the paper web) and up to normal speed about 10 times.

Printing presses require speed regulation within very wide limits. For every press, it should be noted, that a distinction can be made between two definite speed ranges. The lower range is required for the preliminary work *i.e.*, putting on the plates, blanketing the impression cylinders, adjusting and removing the inking rollers, *etc*. This speed should not be greater than will allow of the working of the machine being carefully followed. For flatbed presses this corresponds to from 7 to 8 copies a minute, while for rotary presses it should be possible to obtain 6 to 10 revolutions of the cylinders. It is also very convenient to be able to move the press forward a small distance at a time, known as inching.

The higher speed range is used during actual printing. Here regulation within particularly wide limits is desirable as the type of work, the quality of paper and the skill of the operators may vary considerably. The demands which are made as regards quality of printing also play an important part. The slower the printing takes place, the better it will be although the cost will increase.

Table III.

Readings taken on press No. 4, Table 2. Half press.

Motor	Controller position	R.p.m. press	R.p.m. motor	kW from supply	Remarks
Auxiliary motor	0	0.	0	3.600	At start
	1	8.0	1350	0.485	Continuous at no load
	1	7.5	1300	0.970	Continuous at full load
	2	7.5	1300	0.970	»
	3	8.5	1400	1.020	»
	4	8.5	1400	1.020	»
Main motor	5	62.0	430	13.200	»
	6	67.0	470	14.1	»
	7	72.0	500	14.5	»
	8	76.0	530	14.8	»
	9	81.5	570	15.2	»
	10	87.0	610	15.5	»
	11	95.0	660	15.8	»
	12	100.0	700	16.2	»

Table IV.

Readings taken on press No. 7, Table 2. Half press.

Motor	Controller position	R.p.m. press	R.p.m. motor	kW from supply	Remarks
Auxiliary motor	0	—	—	4.4	At start
	1	4.5	1300	0.640	Continuous
	2	4.5	1300	»	»
	3	5.0	1420	»	»
	4	5.0	1420	»	»
	5	5.0	1420	»	»
Main motor	6	82.5	660	9.45	Series regulation
	7	85	680	9.65	»
	8	85	680	9.65	»
	9	88	700	9.65	»
	10	89	710	9.65	»
	11	90	720	9.65	»
	12	92	740	9.9	»
	13	94	750	9.9	»
	14	95	760	10.2	»
	15	96	770	10.2	»
	16	97.5	780	10.2	»
	17	99	790	10.2	»
	18	99	790	10.2	»
	19	100	800	10.2	»
	20	101	805	10.2	»
	21	102	810	10.2	»
	22	103	820	10.2	»
	23	105	840	10.2	»
	24	106	850	10.2	Normal speed
	25	111	890	11.0	Shunt regulation
	26	115	920	11.5	»
	27	120	955	11.9	»
	28	126	1010	12.5	»
	29	131	1050	13.7	»
	30	138	1100	14.1	»
	31	145	1160	14.6	»
	32	155	1240	15.8	»
	33	160	1280	16.7	»

The qualities demanded by printers of the electrical equipment are:

1) The possibility of obtaining speed low enough to enable preliminary work to be carried out easily.

2) Ability to inch the press.

3) A large range of regulation at the higher speeds.

4) The equipment must be reliable and foolproof, *i.e.*, the apparatus must be simple to operate even by unskilled and careless attendants without possibility of mistake or danger to the equipment.

The meeting of these requirements is chiefly a question of cost. It should never be forgotten that accessability is for printing press equipments of greater importance than for many other installations as the time of going to press is always delayed as far as possible to allow inclusion of the latest news, but if the equipment should break down, even for a very short time, great dissatisfaction is caused among readers of the paper, while capital is always made by competitive papers if an edition is late in coming out.

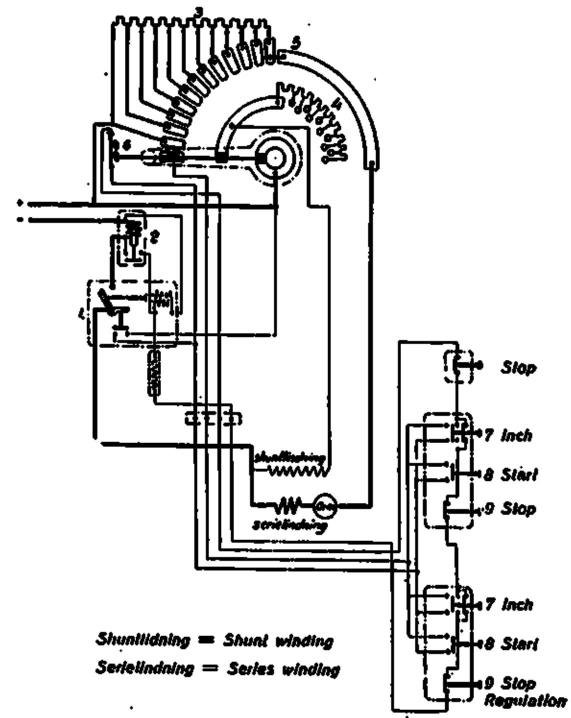


Fig. 4. Diagram of connections for series and shunt regulation.

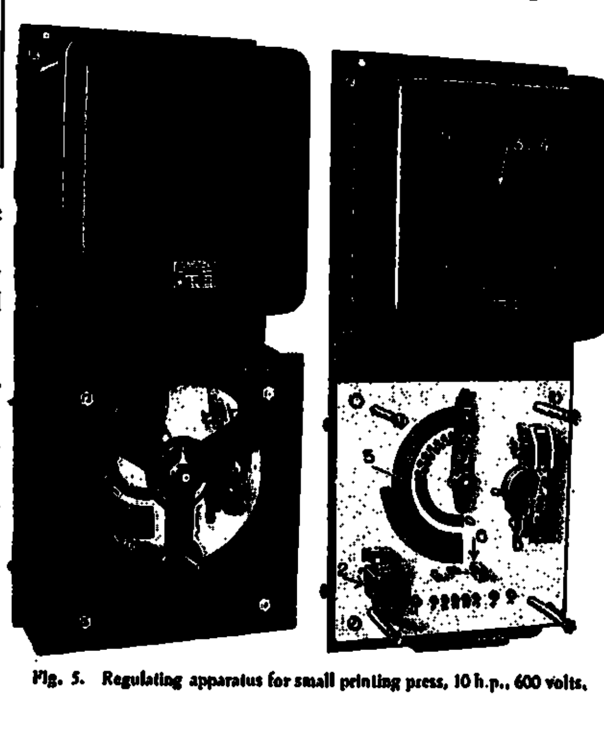


Fig. 5. Regulating apparatus for small printing press, 10 h.p., 600 volts.

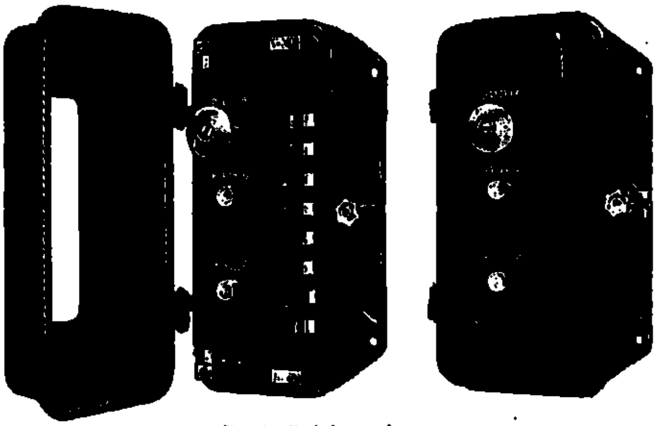


Fig. 6. Push button box.

Different methods of obtaining good regulation.

In selecting an electric equipment the kind of supply available plays a very important part. Attention must also be paid to size of press and the kind of printing to be carried out.

For D.C. a number of different systems have been developed, among which may be mentioned the following:

1) Series and shunt regulation by resistance.

2) Two motor equipment, a small motor for low speed, and a large motor for high speeds. This system is usually known as main and auxiliary motor regulation.

3) Single motor equipment with shunted armature regulation for low speed and series and shunt regulation for higher speeds.

4) A series and shunt motor on the same shaft.

5) Ward-Leonard equipment with speed regulation by variation of generator voltage.

For three-phase A.C. the following are used:

1) Single induction motor with resistance regulation.

2) Single commutator motor with speed regulation by brush displacement.

3) Main and auxiliary motor regulation with a small induction motor for low speeds, an induction motor with regulating resistance as under (1) being used for higher speeds.

4) Main and auxiliary motor regulation with an induction motor for low speeds and a commutator motor for higher speeds.

Lastly the case of single phase supply occurs occasionally. Regulation in this case is best obtained with a motor generator for single phase D.C. and Ward-Leonard regulation for the printing press motor.

Asea furnishes equipments on the following systems for different supplies: For D.C. as under (1), (2), and (3) above, and for three-phase the systems mentioned from (1) to (4).

A more exact description of the various Asea equipments is given later on in this article.

Braking.

It is very important to be able to stop the press quickly. When the paper breaks or if an error is found in the printing *etc.*, the press must be quickly brought to rest and the damage is less the shorter the time required for this. Braking can be effected either by friction or on the electro-dynamic system. The last can only be made use of in the case of D.C. In a

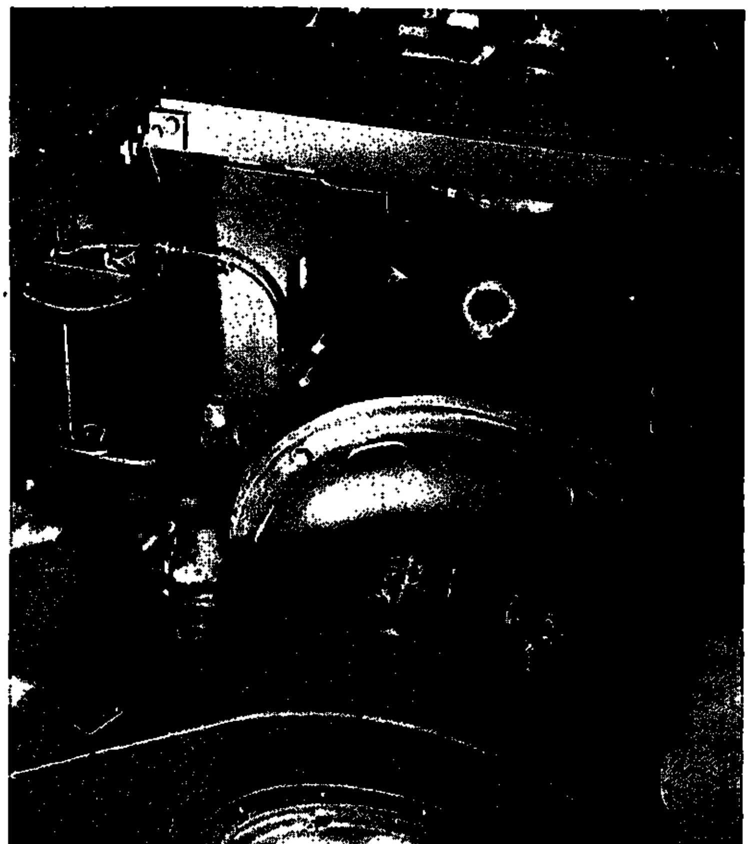


Fig. 7. Machine pit.

number of cases braking arrangements are entirely dispensed with as it has been considered they are not called for by the requirements. The simplest and most common friction brake is made up of a wooden brake block acting upon an iron brake drum. The brake shoe is held on by a weight or better by a spring and is released by solenoid. When the motor is started the brake magnet coil is energised and releases the brake. When stopping the brake magnet circuit is interrupted and the brake is applied. The brake solenoid must always be operated by a separate relay. In the case of D.C. solenoids an economy resistance is also used, *i.e.*, when the solenoid lifts it opens a switch mounted on the cover which introduces a resistance in series with the operating coil. By this means the current is reduced and it is made possible to operate the solenoids continually. A.C. brake magnets do not require such a resistance as they may be continuously connected to the supply without damage. For these last, however, it is particularly important that when closing the moving core should be so connected to the brake that it may come into direct contact with the fixed part of the core. In the case of every A.C. brake magnet this point must be carefully observed otherwise the coil will become too hot and the winding will be destroyed.

Electro-dynamic braking is very effective and can be made fully automatic. As soon as the current is broken a resistance is connected across the armature and the printing press motor runs as a generator on it, obtaining its power from the inertia of the press. This form of brake entails no special arrangements on the press and the braking effect is obtained without the wear of brake blocks and drum occurring in the case of the friction brake.

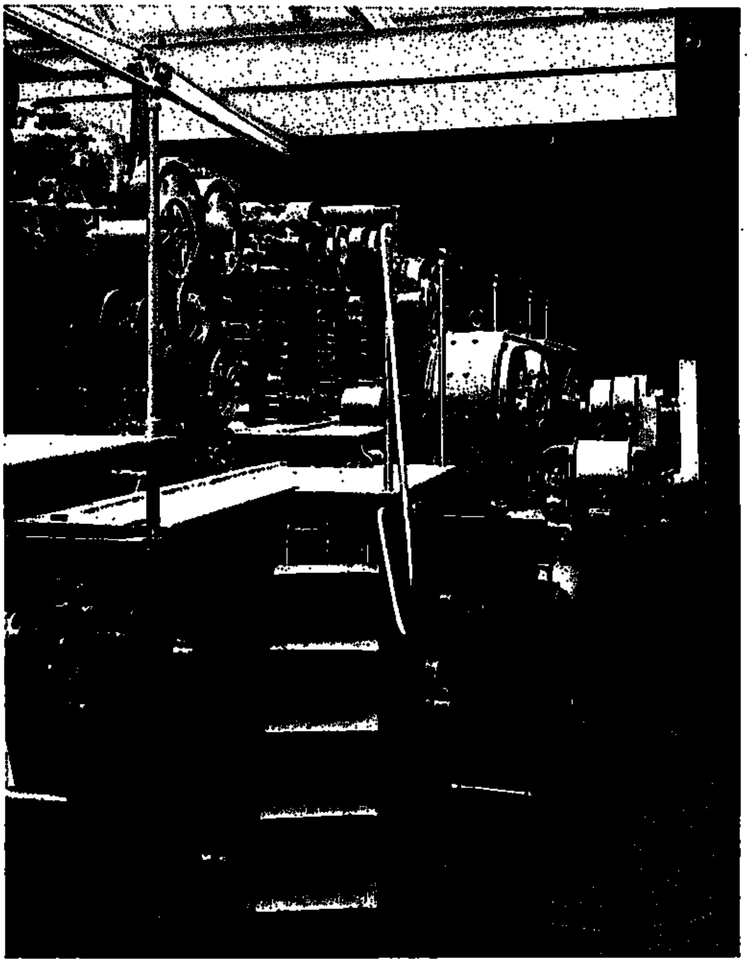


Fig. 8. Rotary press with motors supported at the sides.

Operation.

For printing presses push button operation has been most extensively used. The reason for this is that the printer can devote the whole of his attention to the actual printing. By the simple operation of a button he can completely control the press, and can alter and adjust the speed quickly and easily from any suitable position. The tendency, in all countries is to change over equipments to push button operation even for relatively small presses.

There are in general two systems in use:

1) Semi-automatic push button operation.
2) Full automatic push button operation.

The semi-automatic system employs push button operation only for the lower speed range. For control within the higher speed range manual operation is used. Three push buttons are required in this case. These consist of "start", "stop" and "inch" or "run" buttons.

The "inch" button is used when the press is to be operated at a low speed. The machine runs as long as the button is kept pressed and comes to rest as soon as it is released. This simplifies and accelerates preliminary work and reduces waste of paper. When the preparatory work is completed the "start" button is pressed when the machine runs at its lowest speed. Thereafter the printer can at will adjust the speed to any desired value by operating

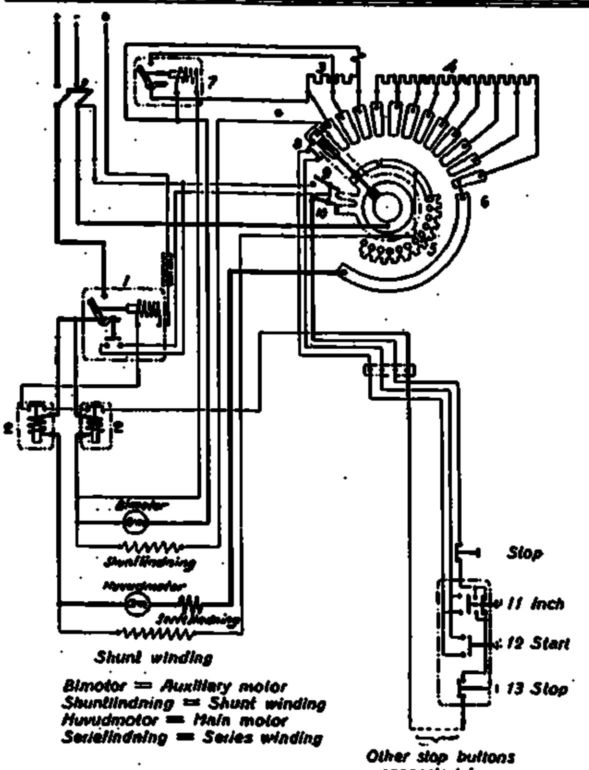


Fig. 9. Diagram of connections for equipment with main and auxiliary motors.

the regulating apparatus by hand. At any time the machine can be stopped by pressing the "stop" button. A number of similar sets of push buttons are arranged at suitable positions on and near the press. This system is provided in addition with overload and novolt relays and interlocking gear so that a new start cannot be made until the regulating apparatus has been returned to the starting position and in this way the motor is effectively protected against carelessness and inexperience.

The semi-automatic system is chiefly used for flat bed presses and small rotary presses.

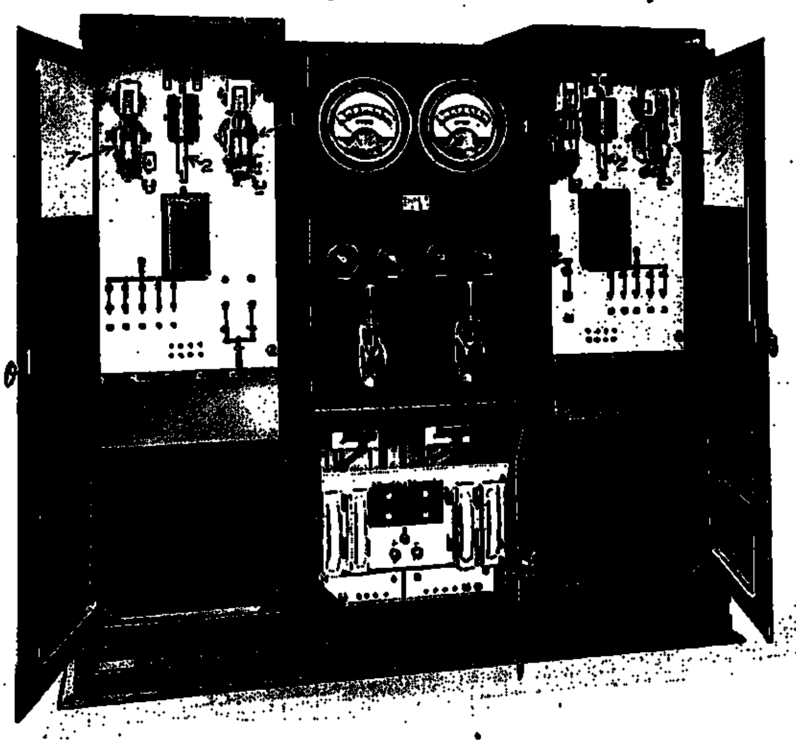


Fig. 11. Switchcase for double press shown in fig. 12.

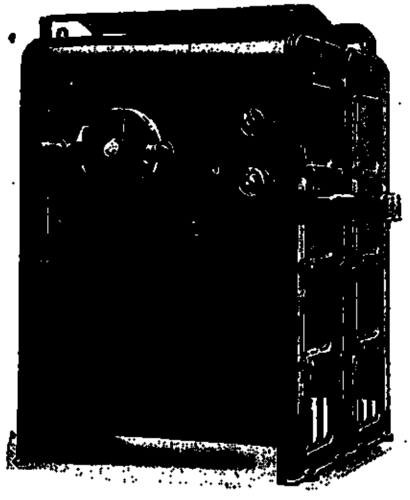


Fig. 10. Gear for semi-automatic equipment.

For large rotary presses and also for all other machines where requirements of space make it difficult to arrange the regulating apparatus close up to the press, the full automatic system is employed. Five push buttons make up a complete set. These consist of "start", "stop", "inch", and "raise" and "lower" buttons. The first three buttons have the same functions as in the case of the semi-automatic system just described. The additional "raise" and "lower" buttons are used when the press is ready for normal running. As soon as the printer has set the press in motion at the lowest speed and found that everything is in order he increases the speed of the machine by pressing the "raise" button. The speed of the press then increases as long as the button is depressed. If the speed for any reason becomes too high it can be decreased by pressing the "lower" button. The speed then decreases as long as this button is depressed.

The presses can be equipped with several push button stations, from any of which operation can be effected equally well. Also to guard against accidents a suitable interlocking system is employed. Here a distinction can be made between the use of a key and a push button for

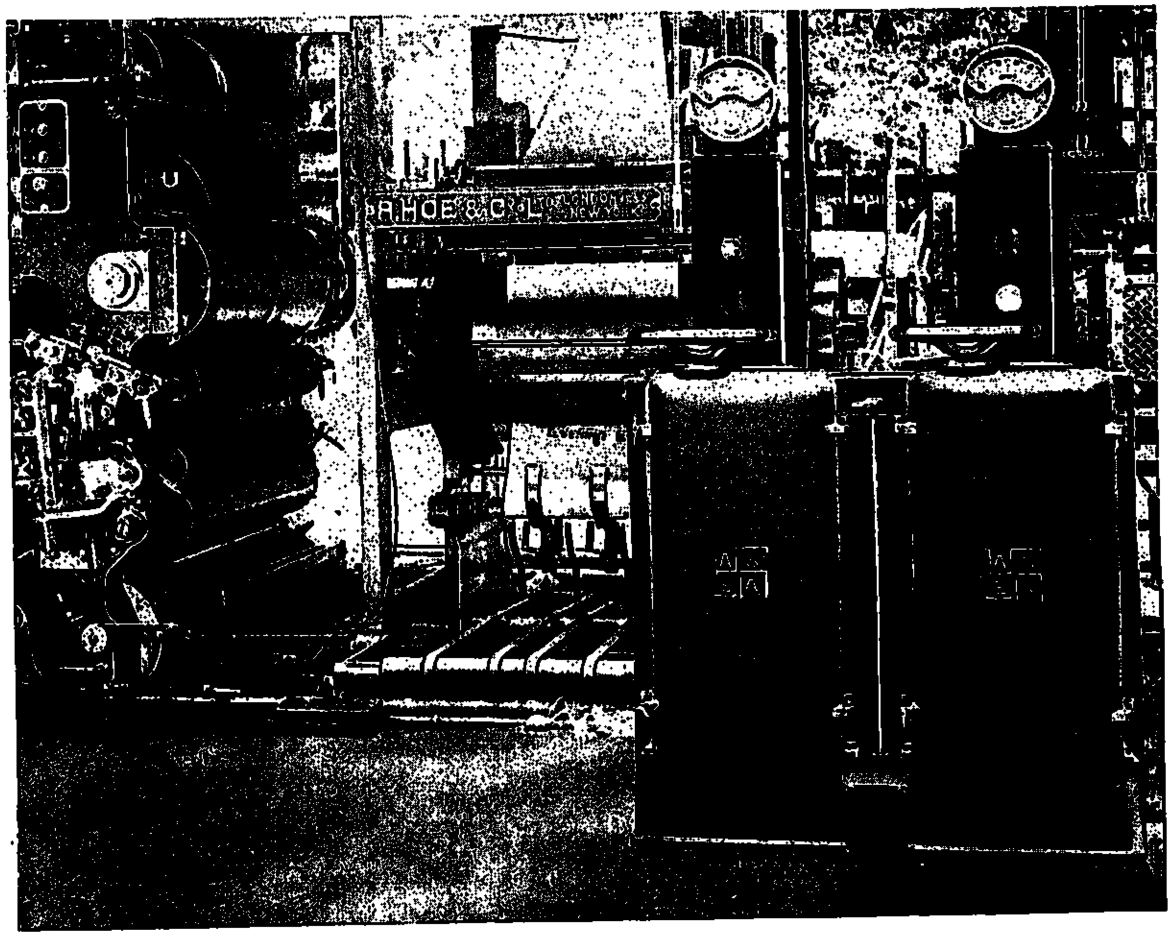


Fig. 12. Twin controller erected at side of press.

making safe. In the former case, one key only is provided which is in the possession of a responsible machine man. It is then only possible to run the motor when the key has been inserted and the interlocking arrangement released. The most common arrangement is, however, to arrange the interlocking in conjunction with the "stop" button. If the "stop" button is depressed it remains in this position and makes the whole system safe. The motor cannot then be started from any other position. It is first necessary to release the interlocking by withdrawing the "stop" button before a new start can be made. The latter system is to be regarded more as a warning and leads to careful working. The former system gives greater security, as long as one key only is used, but in many cases it may give rise to considerable waste of time. In general interlocking by means of a stop button is fully sufficient as long as the personnel are trained and careful.

Lastly a requirement in the case of double presses is that when running in parallel it must be possible to operate the whole as a single press. It must, therefore, be possible to operate the whole double press from either set of push button stations.

The full and semi automatic operating systems can be used for any kind of printing press, irrespective of the kind of supply available.

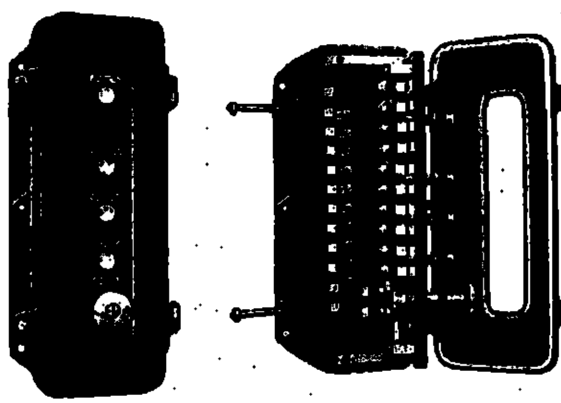


Fig. 13. Push button station.

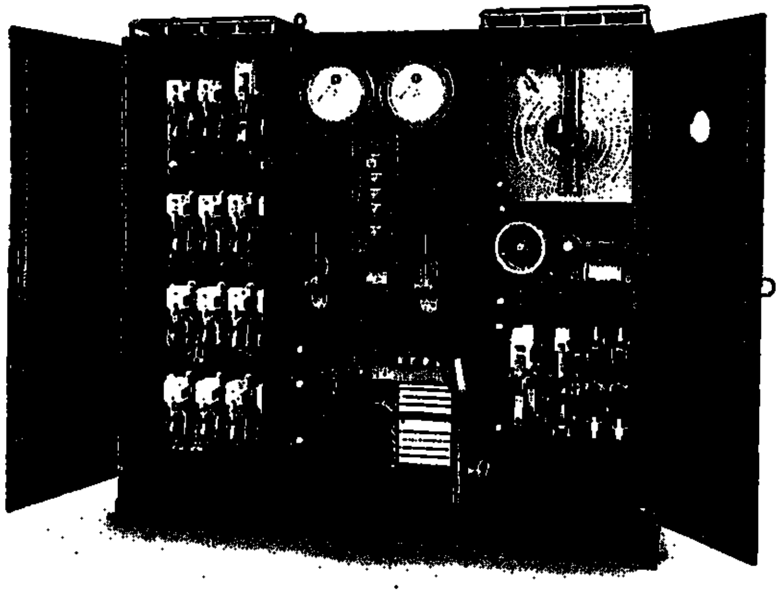


Fig. 14. Switchcase for full automatic equipment.

II. ELECTRIC EQUIPMENTS FOR PRINTING PRESSES USING D.C.

Series and Shunt Regulation by Resistance.

For small presses and in particular for flat bed presses motors with series and shunt regulation are chiefly used. Here a speed regulation of about 4:1 is satisfactory. The lowest speed is used when the press is being prepared for working. The motor is selected with a normal speed corresponding to the normal running speed of the press or somewhat below this value. Shunt regulation is used to give a speed 50 % above this value as a maximum. Although in general we obtain by this method a motor somewhat larger than might be used if the machine were designed with a speed corresponding to the maximum speed of the press, there is usually a considerable saving by the reduction of losses in the series resistance so that the press can be run at lower cost.

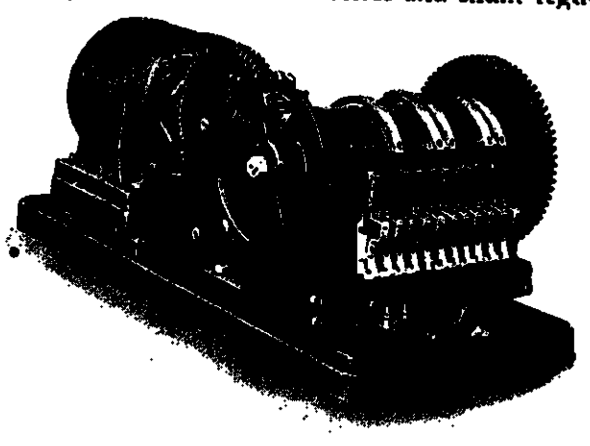


Fig. 15. Motor operated controller.

The equipment is on the semi-automatic system. Only in cases when the electrical apparatus cannot be placed close to the press is a full automatic equipment employed. Fig. 4 shows the connection diagram of a semi-automatic electric equipment.

The series and shunt resistance 3 and 4 are adjusted by the regulating panel 5. The contactor (relay switch) 1 is operated electrically from push buttons 7, 8 and 9, but also functions when the regulator arm passes contacts 6. If, for example, button 7 is pressed the contactor coil is traversed by a current and closes contactor 1. As soon as the button is released the operating current is broken and the contactor opens. If 8 is pressed the coil of this contactor is traversed by a current and the contactor closed. Contactor 1 in this case remains closed until the stop button 9 is pressed. The overload relay 2 short circuits the operating coil for contactor 1 as soon as

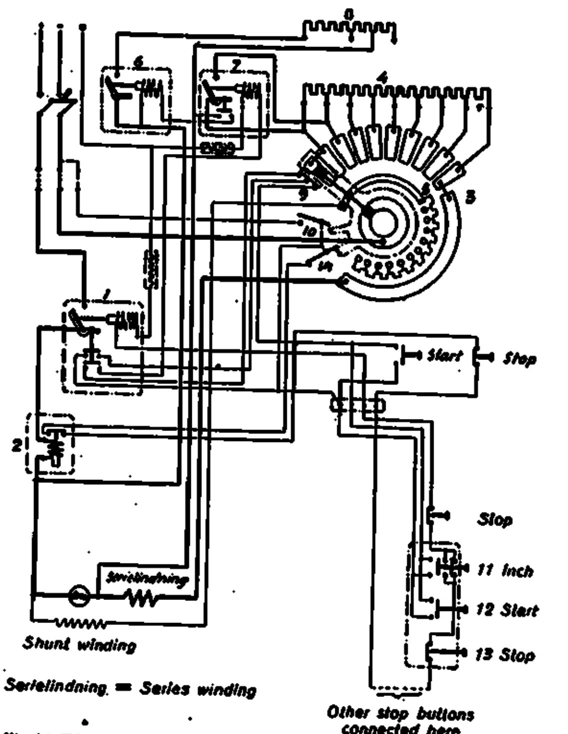


Fig. 16. Diagram of connections for regulation with shunted armature circuit.

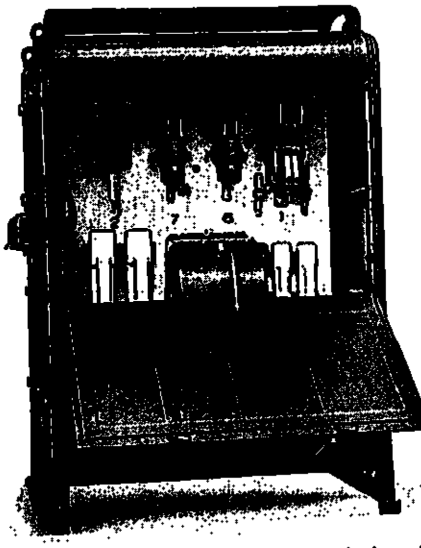


Fig. 17. Apparatus for regulation with shunted armature circuit.

an overload occurs thereby interrupting the main current. If the pressure fails contactor 1 opens of its own accord. In both cases the contact arm of the controller 5 is returned to the zero position before the operating coil can be made to close the contactor again. Fig. 5 shows a switch case for apparatus operating on this system and fig. 6 a push button box. The numbers mentioned above correspond with the numbers on the diagram.

Two Motor Equipment.

(a. Semi-automatic System).

In the system described in the foregoing the maximum amount of speed regulation obtainable is in the ratio of 10 to 1. As, however, in rotary presses, as shown in table II, the maximum speed is about 250 and the creeping speed for preliminary work from 6 to 10 r.p.m. other methods must be used to obtain a suitable regulation at such a low speed. For this apparatus Asea uses a small motor, the auxiliary motor, which by means of a low gearing in the neighbourhood of 24 to 1 can be made to rotate the main shaft of the machine. The gear is connected to an overrunning clutch, *i.e.*, as long as the auxiliary motor is running on a higher speed than the main motor both machines are connected together, but as soon as the main motor shaft runs faster this coupling is released. Fig. 7 shows the machine pit of a printing press equipped in this manner. Fig. 8 shows the motor carried on brackets at the side of the press. Fig. 9 shows the connection diagram for a two motor equipment. The auxiliary motor is operated through the push buttons 11, 12, and 13, but it can only be started as long as the arm of the regulator 6 is in the zero position. This is ensured by contacts 8, 9 and 10 on the regulator panel. When the starting button 11 is pressed contactor 1 closes and the auxiliary motor starts. When it is running about 60 % of normal speed contactor 7 automatically closes and the auxiliary motor runs up to full speed. As soon as the button is released, contactor 1 opens and the motor stops. If the "start" button 12 is pressed the auxiliary motor runs even if this button is released. If the "stop" button 12 is pressed the auxiliary contactor 1 opens and the motor stops. In any case the machine stops as soon as button 13 is pressed. To obtain a higher speed the handle is turned, by which the series and shunt resistances respectively are regulated.

Fig. 10 shows the switchcase for such an equipment. The regulating rheostat can also be disconnected through a controller. Figs 11 and 12 show a semi-automatic equipment for a double rotary press. The figures correspond to the respective numbers on the diagram.

(b. Full Automatic System).

The auxiliary motor and main motor regulation can also be effected fully automatically. On the press is placed in this case a push button station the appearance of which is shown in fig. 13. The five push buttons are marked "inch", "start", "increase", "decrease" and "stop". The operation is effected as described under the heading "operation". The scheme of connections is practically the same as that described under (a) except that the push buttons are increased to five, two new push buttons thus being used for the remote control of the regulating panel. It would take up too much space to

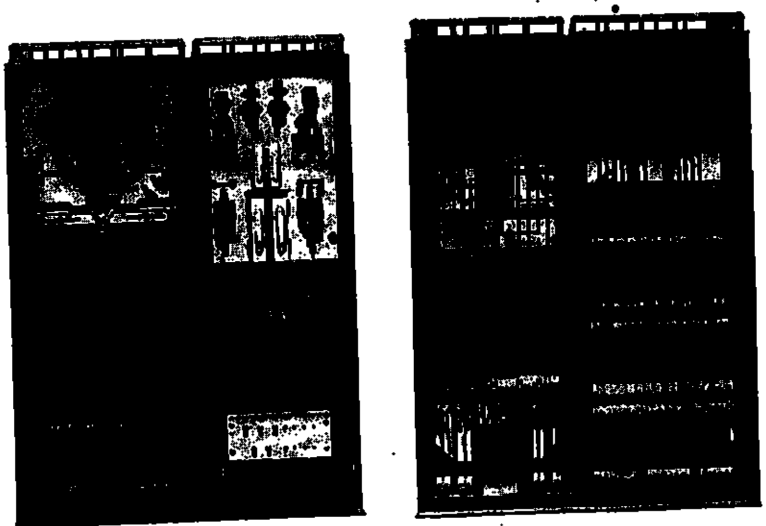


Fig. 18. Full automatic equipment for shunted armature circuit regulation.

describe the connections in detail as they are exceedingly complicated.

The apparatus is shown in fig. 14 which is an illustration of the switchcase for a 100 h.p. printing press. The switchcase contains all the apparatus necessary for the protection and operating of the equipment. All operation is carried out from the push button board. Both inching and speed regulating is effected by electric remote control. Series regulation is effected indirectly through contactors while the shunt regulation is worked directly from the board.

Single motor equipment with shunted armature for creeping speed and series and shunt regulation for higher speeds.

Fig. 16 shows diagram of connections for this equipment. The series and shunt rheostat are regulated on the panel 3 in the usual way and are used for adjusting the press to the normal speed. The creeping speed is obtained by connecting the resistance in parallel with the armature circuit. This connection is effected by the contactors 1, 6 and 7, which have push button operation. On pressing the inch button contactor 1 is energised and thence closed, connecting in turn the energising coil of 7. Contactor 7 short circuits a part of the armature series resistance so that a high starting torque is obtained, making the starting of the press quite certain. Contactor 7 causes the contactor 6 at the side to be connected in circuit and this closes across the armature. This contactor is adjusted to close when the speed, and accordingly the armature voltage, has reached the proper value for the desired creeping speed. When the creeping speed has been reached the resistance 8 is thus connected in parallel with the armature. This resistance is so calculated that the motor runs in a stable manner, giving sufficient torque for the press. It is possible, without using too large a parallel resistance, and thus getting too high losses, to run as low as about 10 % of the normal speed of the motor. If the motor is chosen with the object of obtaining about 300 % shunt regulation it will be seen by a glance at table II that by this method we are able to give a very large amount of regulation (about 30 to 1).

In comparison with the two motor equipment previously described we have the advantage that this equipment is considerably cheaper in first cost, as the auxiliary motor with gearing and overrunning clutch is eliminated. There is, however, the disadvantage that a considerable amount of power is lost in the resistance since the equipment requires when running at the creeping speed approximately the same amount of power as when running normally. The two motor equipment, however, only consumes an amount of energy corresponding to that required by the auxiliary motor and in general this only represents a fraction of the normal amount. (Compare table III). Which of these two methods offers the greatest advantages is thus only a question of calculation. The system just described chiefly comes in question for presses which are only used comparatively infrequently (when printing once or twice a week only). Fig. 17 shows an equipment of this pattern. This type is also made semi-automatic, the electrical equipment being in such a case as shown by fig. 18.

III. A.C. EQUIPMENT.

As a supply D.C. is greatly superior to A.C. both with regard to possibilities of regulation and also cost of apparatus. Accordingly when it is possible to make a choice, D.C. should always be used. Induction motors are wholly unsatisfactory as regards regulation and also with respect to losses when speed regulation is introduced. While a D.C. motor could be regulated without difficulty within limits of 7.5 to 1, if an induction motor is used it is necessary to be content with a regulation of 2.5 to 1. It is, accordingly, only with very small machines such as flat bed presses that a simple motor drive in accordance with (1) could be used. The standard system is the double motor drive with auxiliary motor and main motor. The machines are mechanically connected in the same way as previously described. The electrical connections do not give rise to any greater difficulties. If push button operation is to be

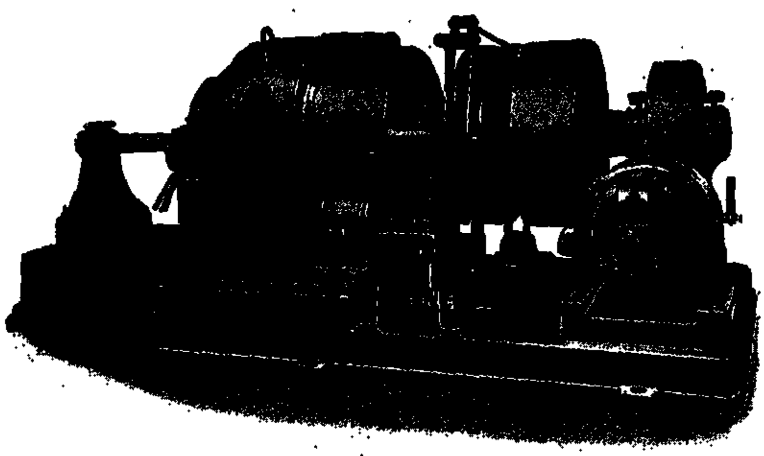
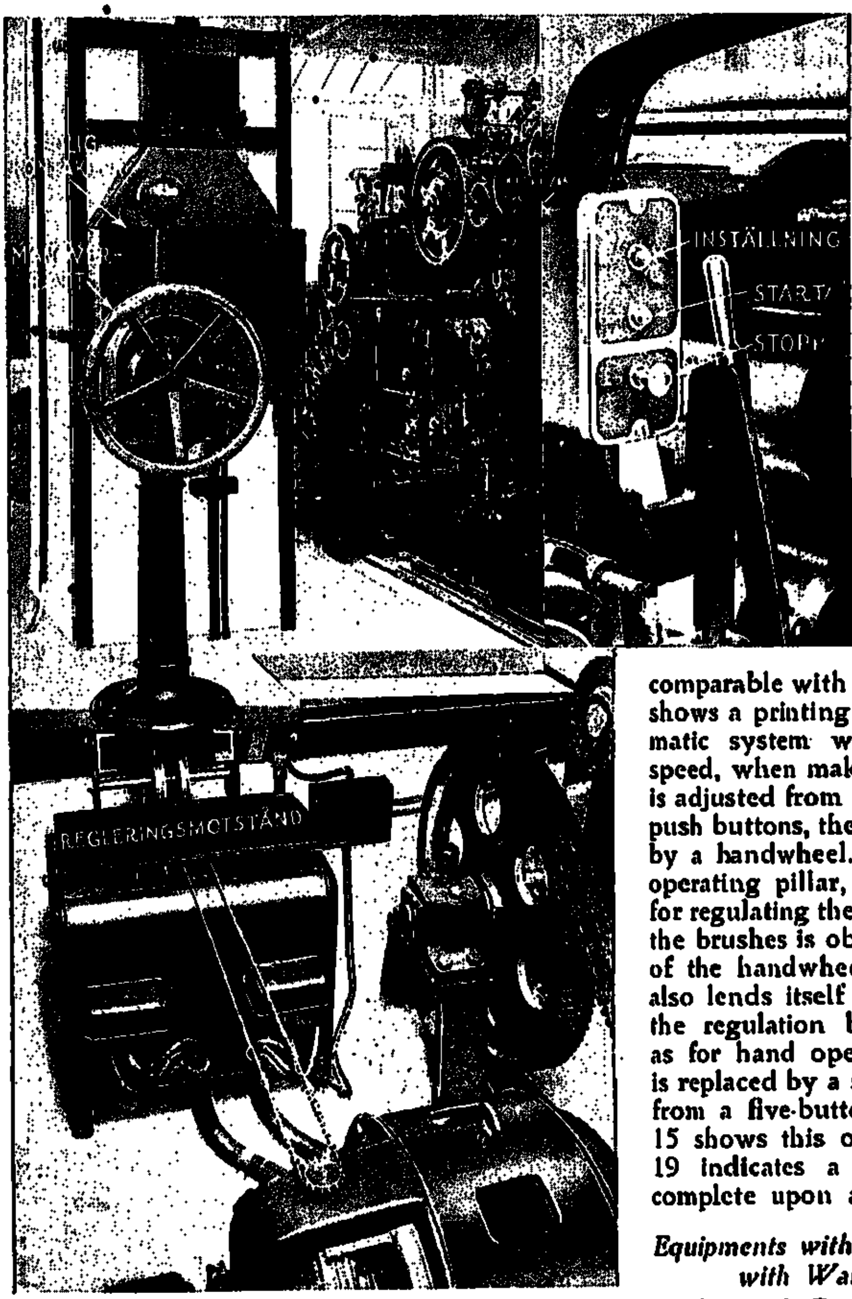


Fig. 19. Apparatus for three-phase printing press motor.



3-polig kontaktor = 3 pole contactor. Manöverratt = Control wheel. Regleringsmotstånd = Regulating resistance. Inställning = Inch. Start = Start. Stopp = Stop.

Fig. 20. Commutator motor equipment for printing press.

used a division must be made between semi- and fully automatic working. Both systems are in use. In this case, push button operated A.C. contactors are used in the primary connections of the motors. The auxiliary motor is provided with a permanent slip resistance, adjustable to give from 20 to 30 % slip, and the main motor with a rheostat regulator covering 40 to 100 % of the normal speed. With semi-automatic working the resistance of the main motor is operated by hand, while for fully automatic working a remote operated controller and contactors are used.

As regards speed regulation a particularly good method with three-phase is to employ commutator motors. The speed is regulated by altering the position of the brushes and when making preliminary adjustments a resistance is used. In this way the speed of a motor can be adjusted in the ratio of 7.5 to 1. If such an arrangement is provided in addition with an auxiliary motor an equipment is obtained which is quite comparable with the D.C. equipment. Fig. 20 shows a printing press drive on the semi-automatic system with commutator motor. The speed, when making preliminary adjustments, is adjusted from a push button box with three push buttons, the normal speed being adjusted by a handwheel. By a special coupling in the operating pillar, the required movement both for regulating the rheostat and also for moving the brushes is obtained by a single movement of the handwheel. This system of operation also lends itself to fully automatic working, the regulation being in principle the same as for hand operation, but the manual drive is replaced by a small operating motor worked from a five-button push button station. Fig. 15 shows this operating mechanism, and fig. 19 indicates a motor equipment mounted complete upon a common bedplate.

Equipments with single-phase and three-phase with Ward-Leonard connection.

With an A.C. supply and particularly in the case of single-phase it has been found an advantage to construct the electrical equipment on the Ward-Leonard system. By this means we obtain particularly good regulating possibilities for the speed of the press. The main connections for such an equipment are shown in the diagram, fig. 21. This diagram shows how the single-phase motor is made to act at the same time as a three-phase generator, the third phase of the winding being made use of for a three-phase supply. This current can then be used for running the three-phase auxiliary motors

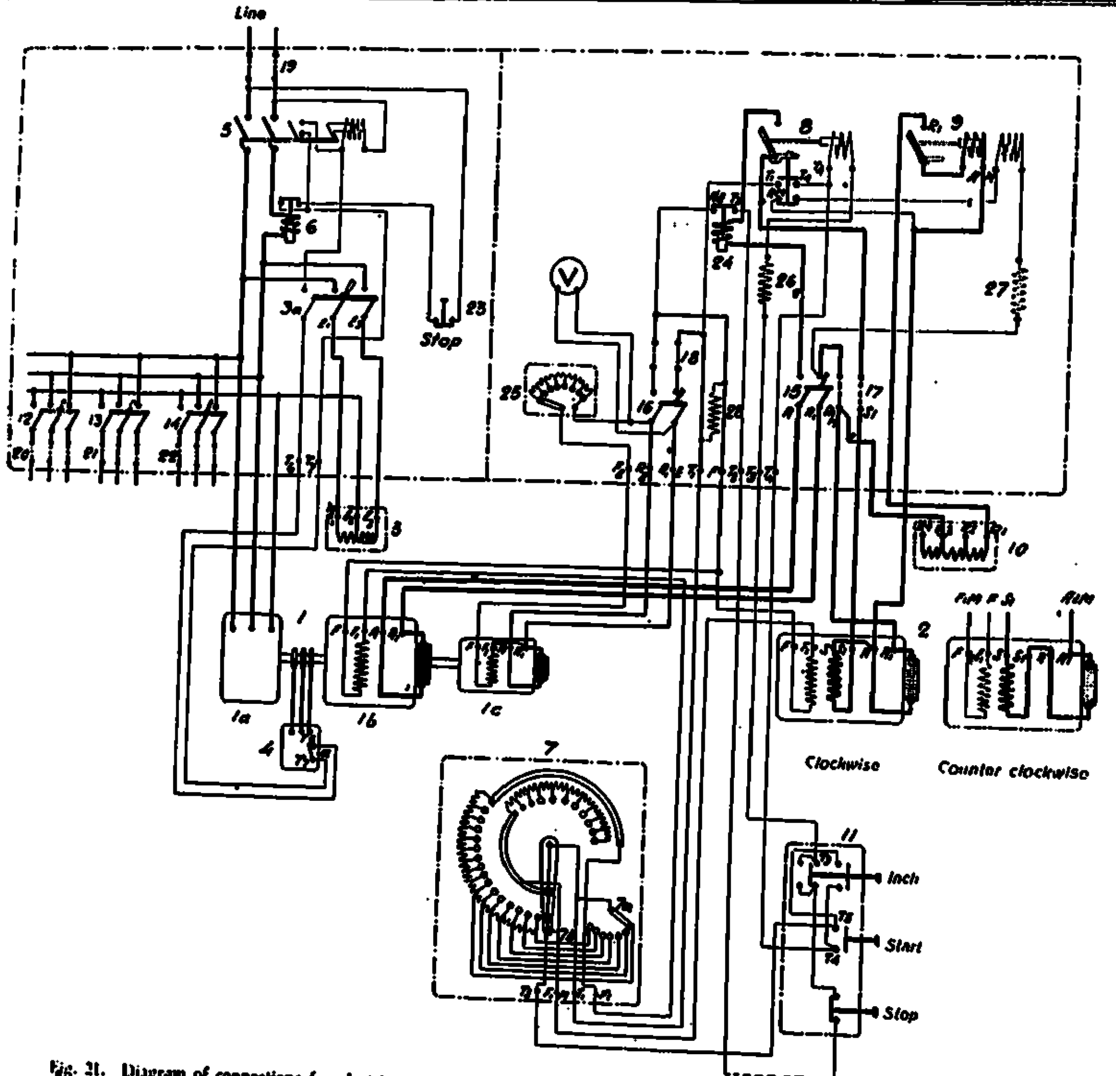


Fig. 21. Diagram of connections for electric printing press equipment on the Ward-Leonard system (single-phase D.C.).

1. Motor generator. 1 a. Single-phase motor. 1 b. D.C. generator. 1 c. Exciter. 2. Printing press motor. 3. Primary starting resistance. 3 a. Starting switch. 4. Secondary starting resistance. 5. Main contactor for A.C. 6. Overload relay for A.C. 7. Field regulator. 7 a. Auxiliary adjustment. 7 b. Interlocking contact. 8. Main contactor for D.C. 9. Brake contactor. 10. Brake resistance. 11. Push button box. 12—14. Disconnecting switches for auxiliary motor. 15. Disconnecting switch for printing press motor. 16. Disconnecting switch for exciter. 17. Fuses for printing press motor. 18. Fuses for exciter. 19. Fuses for single-phase motor. 20—22. Fuses for auxiliary motors. 23. Stop button for single-phase motor. 24. Overload relay for D.C. motor. 25. Field resistance for exciter. 26. Series resistance for contactor 8. 27. Series resistance for contactor 9. 28. Parallel resistance for field.

required in the printing works, for instance for boring boxes, circular saws, *etc.* The motors for such machines are of ordinary three-phase type with standard pattern starters.

The equipment of electrical machines for the press consists of a motor generator (marked 1 on the diagram) which is made up of a single-phase motor, a D. C. generator with separate exciter and the driving motor for the printing press (marked 2). The apparatus for the A.C. side consist of primary contactors 5 with over-load and no-volt releases. The primary starting resistance is marked 3 and the starter 4. In addition to the above, standard fuse gear is used.

The D. C. equipment includes in addition to standard field resistance and fuses a special field regulator for the generator and motor fields (marked 7), the main contactor 8 and the brake contactor 9, with brake resistance 10.

Working is on the semi-automatic system. The speed for making preliminary adjustments, inching and stopping, is arranged from a push button board, 11. The push buttons on this board control the operating current for the contactors 8, and the same system has already been described. Speed is regulated by the field regulator 7 in the ordinary way.

The brake is automatically applied to the press as soon as contactor 8 is opened, the auxiliary contact on this connecting the winding of the

brake magnet to 9. The brake contactor 9 connects the brake resistance in the armature circuit so that a current traverses the resistance and applies the brake to the machine. As long as the press remains running the braking current is maintained at a high value and contactor 9 is kept closed. As soon as the press comes to rest, 9 is released and the brake is taken off.

The equipments which have been described above are representative of the most important general types and may be considered to meet all the requirements which exist at present. With these types we are in position to supply electric drives for all types of printing presses and to ensure that the arrangement will be the best and most practical.

During the last few years Asea has manufactured a number of electrical printing press equipments in accordance with the principles we have described. In carrying out this work we have been in the closest co-operation with the printing trades and have obtained full information as to their points of view and requirements, and we are fully acquainted with the demands exacted by printers.

We have striven throughout to provide the simplest possible machinery in every case, bearing standardisation in mind and to give our equipments that simplicity of operation and quality of regulation which is most desired. As, however, cases often occur where special arrangements have to be designed and put forward, we would remind our readers that every new equipment is always given the most careful consideration and we can guarantee that the machinery supplied will run satisfactorily.

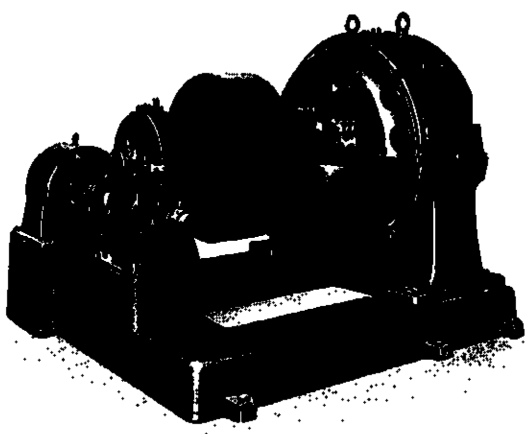


Fig. 22. Direct current motor equipment consisting of pilot motor, main motor, wormgear and overrunning clutch, driving the press shown on the front page of this issue.

ASEA PLANT IN PALESTINE.

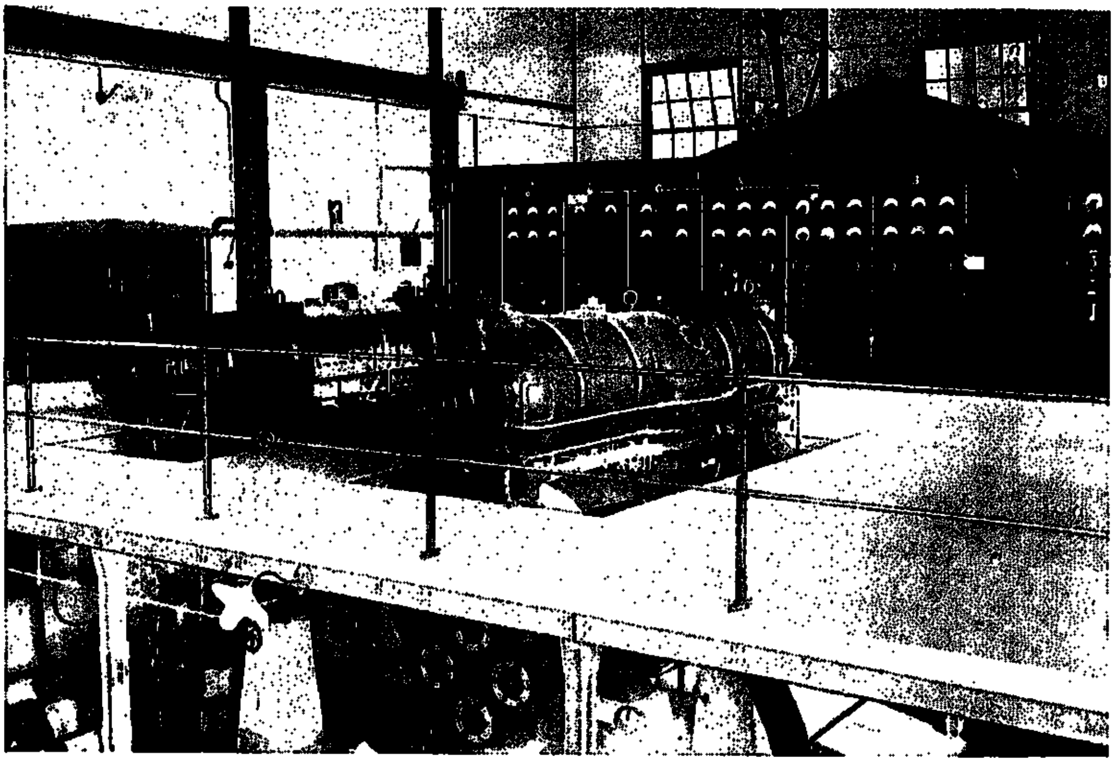


Fig. 1. Interior of power station.

In the latter part of 1924 and at the beginning of 1925, Asea obtained orders from the Portland Cement Company (Nesher) Haifa, Palestine, covering a large equipment including turbo generators and switch gear for a power station and various motors for cement works. This plant is situated at Nesher in a place about five miles from the town of Haifa between the Mediterranean and Mount Carmel, from which latter place the raw material is transported to the cement mills over a telfer line.

The place where the Works are built was formerly desert. No rain falls here from the middle of April until the middle of October when the rain season commences, when there is a long period of thunderstorms and tropical rain. During the hot weather the temperature reaches 50°C in the shade. The works in question represent one of the foremost industries in Palestine, and employ about 160 men, the maximum output being 240 tons of cement per day; this quantity being entirely absorbed within the country.

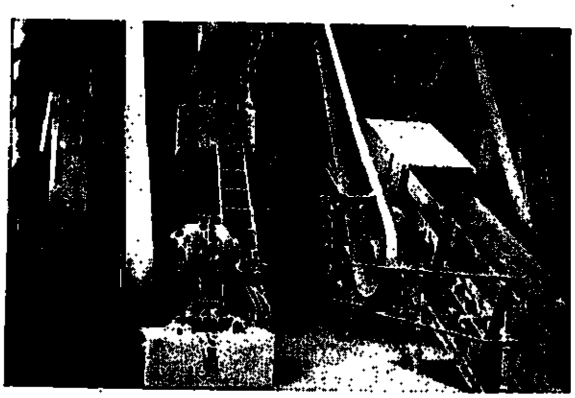


Fig. 2. Asea motor driving mill and conveyor.

Fig. 3. Pumping unit for supplying water to the mill.

g. 4. 120 h.p. motor and starter. Distribution board in the background.

The power station is equipped with two Stal rbo-generators of 1,200/1,667 and 667/933 kVA spectively at 3,000 r.p.m., 400 volts, power factor 75, Y-connected, 50 periods. In addition to iese machines, a three-phase generator of type ; 17, 55 kVA, 400 volts, 375 r.p.m., 50 periods, as supplied somewhat earlier, and this machine driven by a Diesel engine, being used for ghting purposes on days when the other iachinery is not running.

The switchboard is of the self-supporting, all

Fig. 5. View of the mill.

steel pattern, comprising ten panels, four generator panels being placed in the centre. Of these panels one is at present blank, and has been included in case need should arise in the future for an additional turbo-generator set.

The oil switches, current and pressure transformers, fuses and switches for the outgoing motor feeders are erected on a framework in the rear of the board, and of the six distribution panels one is arranged for lighting, and the remainder feeder cables are run to 10 distribution boards of type GS and GSH located in different parts of the works.

The cement mill is fully electrified, and the rotating roasting ovens, ball mills, cement mills and drying ovens, are all run by Asea motors. In addition, motors have been supplied for running the belt transporter, workshop, laboratory and cask factory, also for the pumps in the boiler-house and pump station. All motors are

Fig. 6. Asea and Stal erectors with native labourers.

specially insulated for use in tropical climate, and are wound for 380 volts, 50 periods, the sizes ranging from 2 to 120 h.p. Altogether about 50 motors, having a total output of 1,200 h.p. have been delivered.

The motors are all provided with special bearing packings to keep out cement dust, and the windings are coated with a special varnish to which cement dust does not adhere.

The whole of the erecting work on the turbo-generator and electrical equipment has been carried out by erectors sent by Asea and Stal, with the help of native labour.

The customers have expressed entire satisfaction with the quality of all the material supplied and with the manner in which the work has been carried out, and it is hoped that this first large plant for Palestine will constitute a good advertisement for Asea and for Swedish manufacturers in general.

Fig. 7. View at Haifa.

MINING HOIST AT GRANGESBERG, SWEDEN.

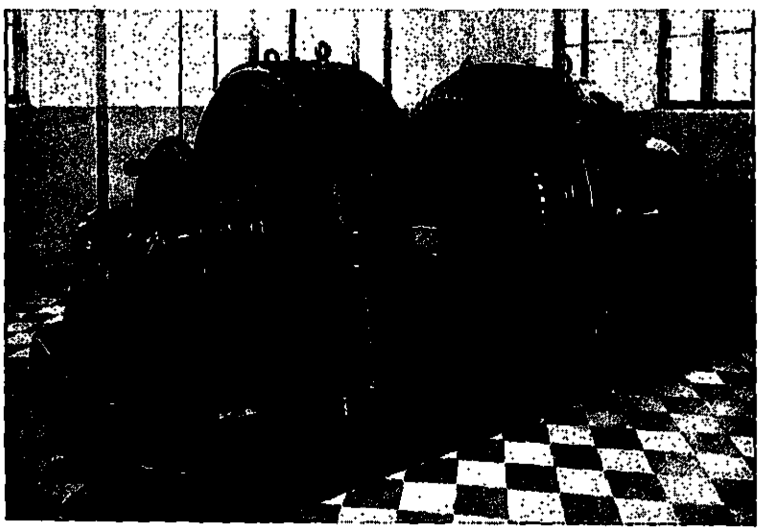
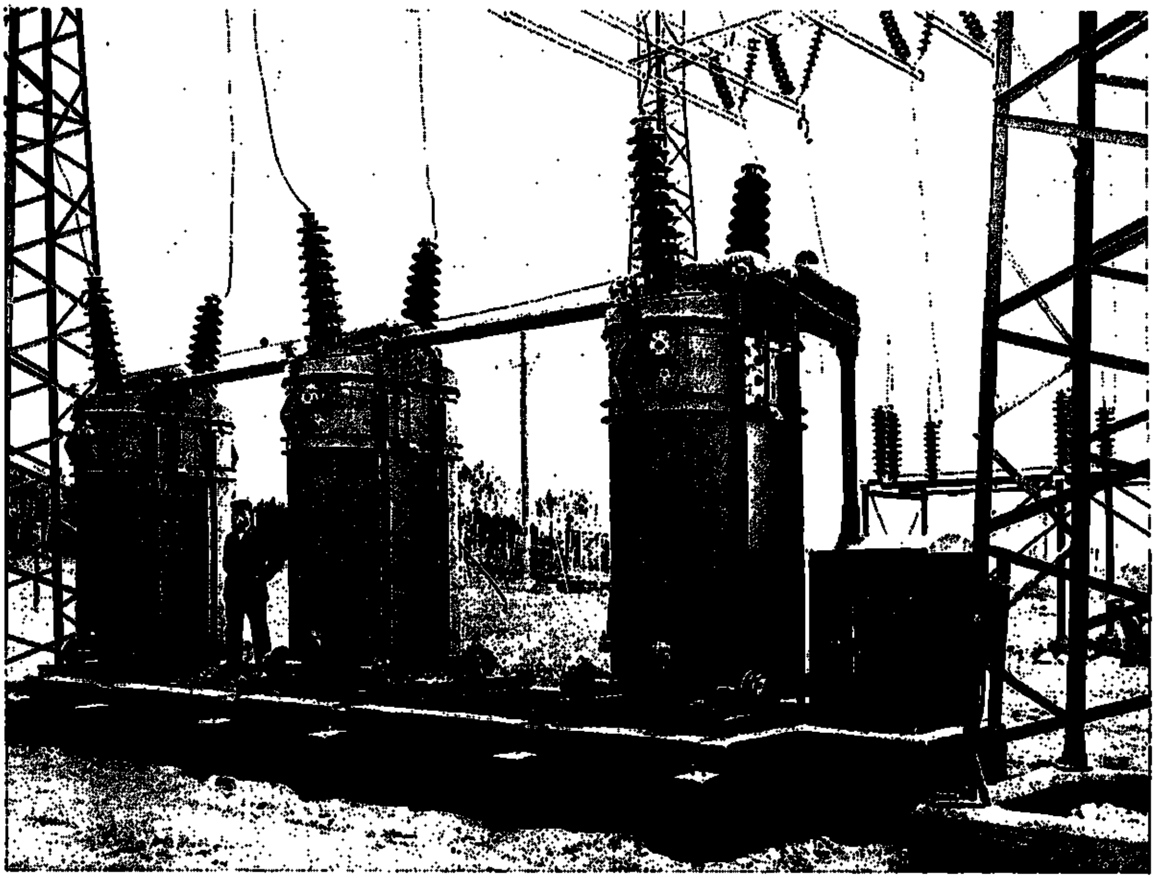


Fig. 1. Motor generator.

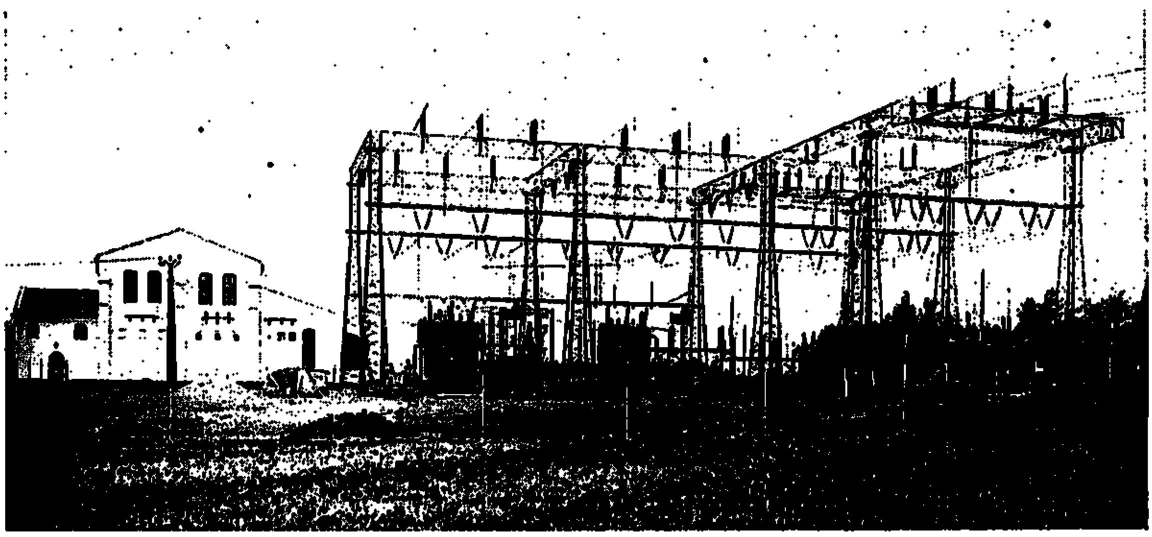
The illustration at the side shows the motor generator set for a large mine hoisting gear supplied in 1924 to the Grangesberg Co., for the Mullers pit at Grangesberg, and consists of a self-starting synchronous motor Type G 149, 1,200 kVA, 3,300 volts, 50 periods, 60 r.p.m., cos $\varphi = 0.7$, mounted on the same bed-plate and direct coupled to, a separately excited D.C. generator Type K 22, 750 kW, 5,500 volts, and an exciter Type K 13, 51 kW, 240 volts. The synchronous motor runs at present on a 60 period, 4,000 volts supply at a speed of 720 r.p.m. but is designed for use in the near future on a 50 period, 3,300 volts circuit. The D.C. generator is connected on the Ward-Leonard system to two series-connected winding motors, each direct coupled to each half of the drum, and each having a normal output of 375 kW at 275 volts, or when connected in series, 750 kW at 550 volts. Fig. 2 shows the winding gear, with one of the winding motors and drums, and the control platform. With a generator voltage of 550, the winding motors run at a speed of 40 r.p.m., corresponding to a rope speed of approximately 8 m/sec. The winder which has a capacity of approximately 7 tons of ore per cage, is equipped with all modern safety devices which practically eliminate all risk due to incorrect operation. The synchronous motor of the motor generator is connected to the supply through a three-phase water cooled transformer delivered at the same time, having an output of 1,200 kVA and wound for 7,500 ± 5 %/3,150 volts at 50 cycles, or 9,000 ± 5 %/3,780 volts at 60 cycles respectively, the continuous output on the higher frequency being 1,440 kVA. This transformer is also made to act as an auto-starter for the synchronous motor. The working conditions for this equipment are particularly arduous. As an example of this it may be mentioned that the D.C. machines during normal winding have to withstand load currents of 2,400 amps. at all voltages from + 550 to − 550 and in exceptional cases (*i.e.* when making an emergency stop) must withstand without damage sudden current surges up to 3,000 amps.

Fig. 2. Large winding gear at Mullers pit.

CURRENT ILLUSTRATIONS.



3-pole automatic electrically operated oil switch type HYGEU 130/350, 132 kV, 350 amps., erected at the Swedish Government outdoor transformer station at Moholm.



Outdoor construction at Moholm, Sweden.

Vesteras 1927, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

ALLMANNA SVENSKA ELEKTRISKA A.B.
VESTERAS — SWEDEN

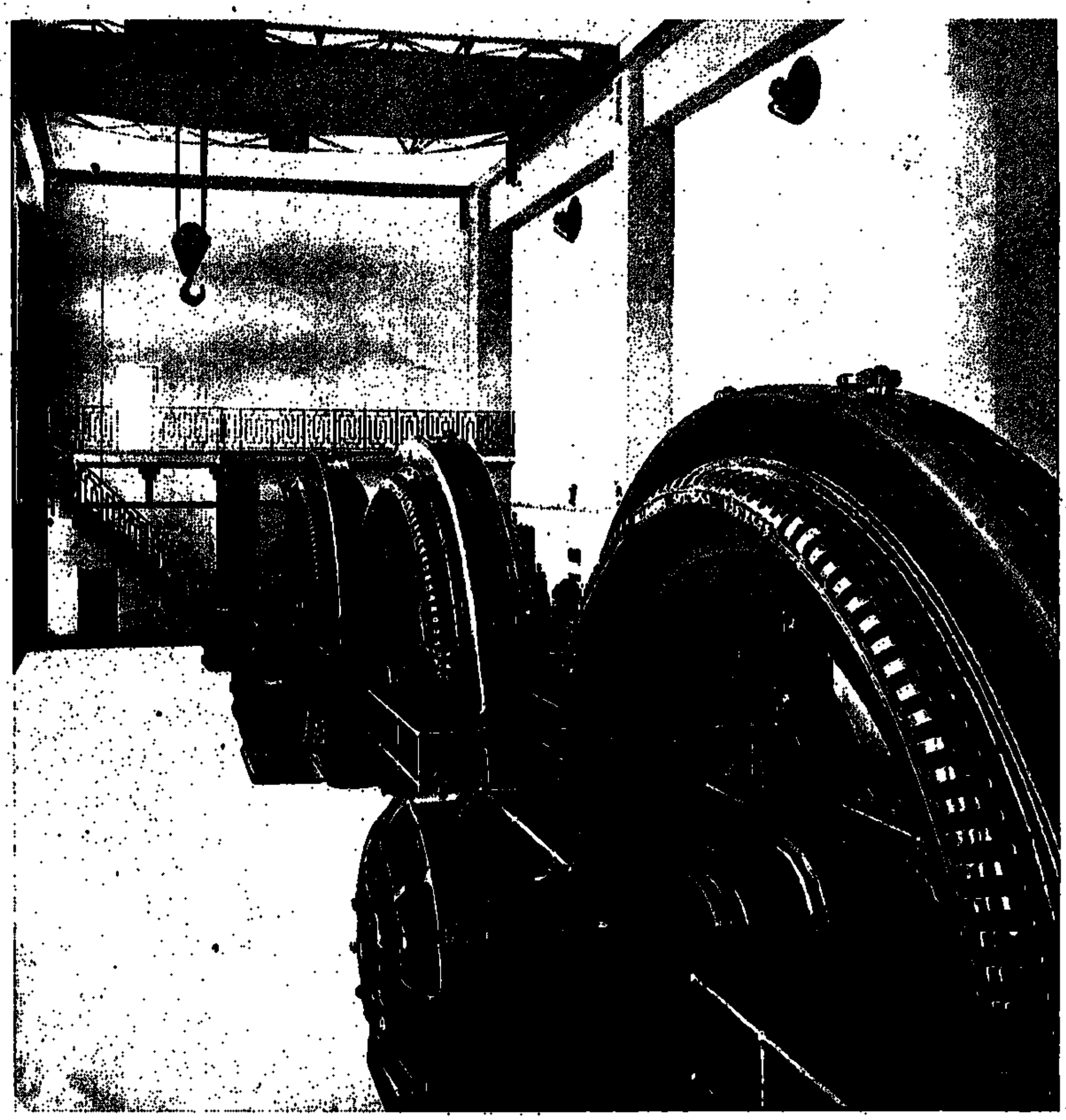
SWEDISH GENERAL ELECTRIC LTD
5. CHANCERY LANE—LONDON

MONTHLY REVIEW

VOL. IV 1927

MARCH No. 3

All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesteras, Sweden.



Interior of the power station of the Holmens Bruks & Fabriks A.-B. at Norrkoping, Sweden. Three 4,250 kVA, three-phase generators, 150 r.p.m., 50 cycles, 3,000 volts.

POWER STATION OF THE HOLMENS BRUKS & FABRIKS A.-B., NORRKOPING, SWEDEN.

One of the largest of the complete power stations built in Sweden within recent years, for private owners, is the installation known as the Bergsbron—Havet station of the Holmens Bruks & Fabriks A.-B. at Norrkoping.

Since very early times the water power available from the Motala river has been harnessed for practical use and this is particularly the case within the town of Norrkoping where the last falls of the river are located before it empties into the sea. In the seventeenth century flour mills, saw mills and brass finishing factories existed in this town and the spinning and textile industry had an even earlier hold on the district. At the commencement of the nineteenth century a paper mill was started here and this was later taken over by the Holmens Bruks & Fabriks A.-B. which built here one of the first installations in Sweden for wood pulp manufacture, and also textile mills. A number of factories of other kinds involving products such as wool, sugar, matches etc. took over sites on the banks of the river, and the power was utilised through a number of water wheels which later gave place to more modern turbines. At the commencement of the present century all the power had been developed, with the exception of two falls in the lower part of the river and great difficulties began to arise regarding a fair division of the water power available, among the different works. Certain rules regarding water rights were drawn up but numberless complications were continually cropping up. At this period a proposition was brought forward for the electrification of the whole of the available water power from the level of Lake Glan, a few miles north west of Norrkoping, down to the sea level and to distribute the power obtained to the various owners of the separate falls. Several suggestions were made and rejected and at last a less comprehensive plan was taken in hand, dealing only with the electrification of the water power from a bridge known as the Bergsbron in Norrkoping down to the sea level, involving the construction of a power station on the site occupied at that time by the Langasen Power Station. As the largest owners of water rights on this stretch of river the Holmens Bruks & Fabriks A.-B. undertook the construction of the new power station, the Company having at various times taken over the rights of about a dozen other water power owners.

As reserve power from a steam driven station was available to a sufficient extent it was decided to design a power house for a flow of 115 cubic metres per sec. although the lowest flow recorded is as low as 40 cubic metres per sec. At the other time, the flow may upon occasion reach 360 cubic metres per sec. The height of fall is fixed below the power station by the sea level, and above the power station by the fixed height of water from the tail race of the power station at Bergsbron. Normally this height is 11 metres. The power available is, in that case, approximately 13,000 h.p. which represents a considerable increase on the power which could be obtained from the former stations. Above the power station water flows in the existing riverbed which has, in places, been deepened by blasting, and just above the station through a canal approximately 150 metres in length, 6 metres deep and 16 metres broad, having reinforced concrete walls with their foundations in the solid rock. Extending from below the power house the river bed has further been deepened over a stretch of about 300 metres for the tail race and at the power house itself is 5.1 metres deep with a breadth of 35 metres at the bottom. The masses of stone which had to be blasted out were used for filling in the site of the old works and various other spaces along the river, thus enabling a consider-

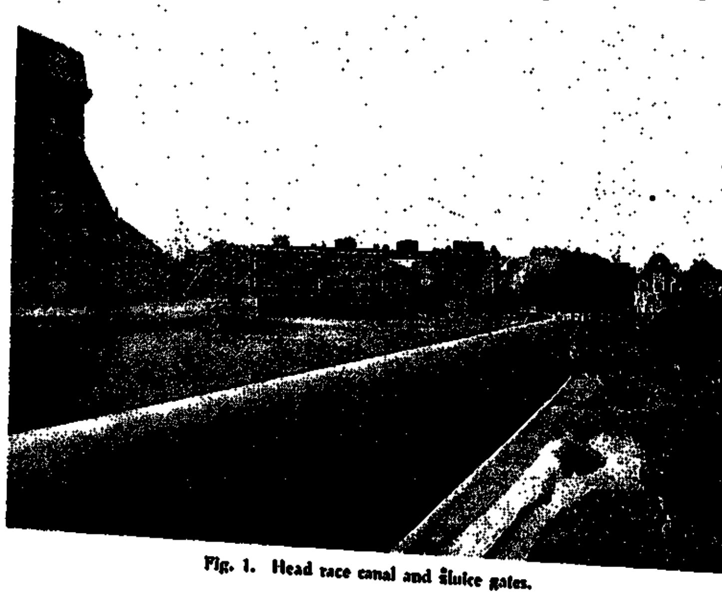


Fig. 1. Head race canal and sluice gates.

able amount of land to be reclaimed. The most modern arrangements have been installed for controlling the water.

The power has been divided among three units consisting of water turbines of the Francis type, having direct coupled three-phase generators and exciters. Double runner turbines have been used, having horizontal shafts and these are erected in open pits. They differ somewhat from ordinary double runner turbines in that each wheel is provided with a separate suction pipe, the outer wheel being also overhung, so that the suction pipe does not require to be provided with a bearing and is not penetrated by the shaft. The governors are both driven in the usual way and are placed at the up-stream end of the power house. The turbines are designed for 4,780 h.p. with a water quantity of 41.1 cubic metres per sec. and, during official tests with this load, were demonstrated to have an efficiency of 82.5 % approximately.

The three three-phase generators are connected to the turbines, the shafts being supported by two ring-oiling pedestal bearings. They are of the Asea standard pattern, type G 275 and are designed for a continuous output of 4,250 kVA at 150 r.p.m., 50 periods, 3,000 volts and $\cos \varphi = 0.75$.

For convenience in transport the stator is divided in halves, and is also provided with removable feet so that it can be lowered upon and turned round with the rotor when one foot has been taken off. This makes every part easily accessible in case repairs are to be carried out.

The rotor is manufactured with magnet ring arms and boss of cast iron in one piece. As some alterations were made in the turbine design it became necessary to increase the original flywheel capacity of the generators, and also to build them for a considerably higher runaway speed than was originally intended, and on this account the rotors were provided with steel side rings shrunk on the cast iron magnet ring. The pole cores are made in one piece with the pole shoes, from cast steel, and are fixed to the magnet wheel by heavy bolts screwed into them from the inner side of the ring and thus easily accessible for dismantling, without interfering with other parts of the generator. If a breakdown should occur in a field coil the pole can easily be removed in the axial direction together with the coil, after the securing bolts have been taken out. The boss is split at the shaft and is held together by steel shrink rings. As finally constructed, the field magnet wheels have a flywheel capacity of 385,000 kgm² and are built to withstand a runaway speed of 340 r.p.m. corresponding to an overspeed of 127 %.

The exciters are designed for a continuous output of 55 kW at 230 volts, which corresponds approximately to the maximum requirements of the generator fields.

With the generators and exciters necessary regulating resistances were supplied, and these are placed in a separate room in the switchgear building and operated by push buttons from the control room.

Generators and exciters are exceedingly conservatively designed. The temperature rise after continuous full load does not exceed 75 % of the values allowed by the Swedish Technical Society rules. At the same time, an effort has been made to attain the highest possible efficiency. On the official tests an efficiency of 96.4 % was attained at full load with efficiencies of 95.8 and 94.0 % at three-quarters and half load resp. In other respects the generators are entirely standard, and the measured voltage rise when throwing off full load was found to be 24 %, while the short circuit current with no-load excitation is 119 % of full load current, corresponding to a short circuit current with full load excitation of 1,865 amps or about 2.3 times normal full load current.

On account of the low speed the machines are of rather large size; the breadth over the stator feet is 7.23 metres,

Fig. 2. Operating passage in high tension switch room.

Fig. 3. Busbar chambers.

the length from the flange on the shaft to the extremity of the exciter 4.54 metres, and the height above floor level 4.4 metres, while the lowest point is 2.1 metres below this level, the machine pit being 2.5 metres in depth. The total weight of a generator is approximately 57 tons, of which the stator represents 23 tons and the rotor 26 tons, the rest being taken up by the bedplate, bearings, etc. The exciter weighs 5 tons. From the generators the power is taken through cables to the switchgear, which is housed in the old St. Andrew's Mill, which has been completely rebuilt and turned into a modern switchgear building with three floors. All the cables are brought in here from the new power station, from the existing power station at Krakholmen, from the power station at Laxholmen and from the steam station of the Company, and the power is led out from this building to all parts of the undertaking, and also to consumers who originally had rights in the water power. The cables are taken to the mill in a duct under the power station and by means of a special bridge over the river.

The switchgear is arranged with the incoming line oil switches and apparatus on the first floor. Here also is placed a station supply transformer of 600 kVA and 3,180/400 volts of the oil immersed indoor pattern. Space has further been reserved for a 20 or 40 kV transformer installation so that there will be no difficulty on the ground of space, if it is desired in the future to run in conjunction with the Government supply lines, with the Norrkoping municipal plant or with any other large power station.

The busbars have been placed on the second floor where there is also a special room for the field rheostats of the generators and exciters. Finally, the third floor contains apparatus and switchgear for the outgoing feeders and the accumulator battery for the control circuits. This battery is also of sufficient capacity to act as a standby for one of the exciters. On the same floor has been placed the control room for the power station, and this is equipped with necessary switchboards and benchboards.

Low tension power is supplied at 220 volts for the D.C. section and 380 volts for the A.C. section. The high tension supply is 3,000 volts. All the high tension apparatus is, however, of the 6,000 volt type and has been tested with 40,000 volts. All the oil switches have a short circuit breaking capacity of 45,000 kVA; those used for the incoming lines are arranged for electric remote control. In the switchgear building two cables are run, partly under the floor and partly through ducts in the wall. The floor has accordingly been arranged with concrete slabs above the cable supports and a filling of limestone chippings put in round the cables. The finished surface of the floor is of tiles laid on loose and which can easily be taken up and re-laid if it is necessary to take up or alter one of the cables.

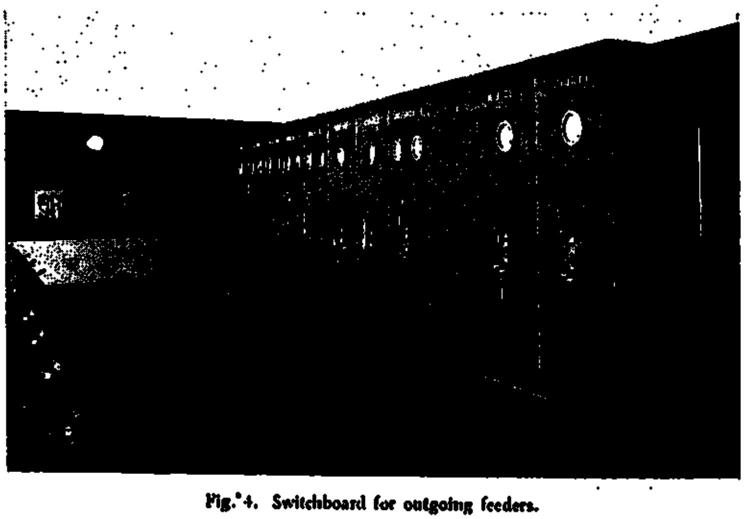


Fig. 4. Switchboard for outgoing feeders.

In the switch gear building is also a spare motor generator set for the excitation and a charging set for the accumulator battery.

The switchgear building and the power station are both warmed by the heat developed in the generators. The cooling air is brought to the switchgear building through a duct connected to the cooling system in the power house, and a fan, capable of dealing with 8 cubic metres per second, has been installed. The heated air obtained from one generator only is sufficient for all the warming. Three fans have been arranged in the power station wall, discharging into the turbine pits so that the heated air, which is not otherwise required, is discharged over the surface of the water to the fish guards, and in this way the formation of ice in winter time is prevented. During times when the power station is not running heating is provided for by electric radiators.

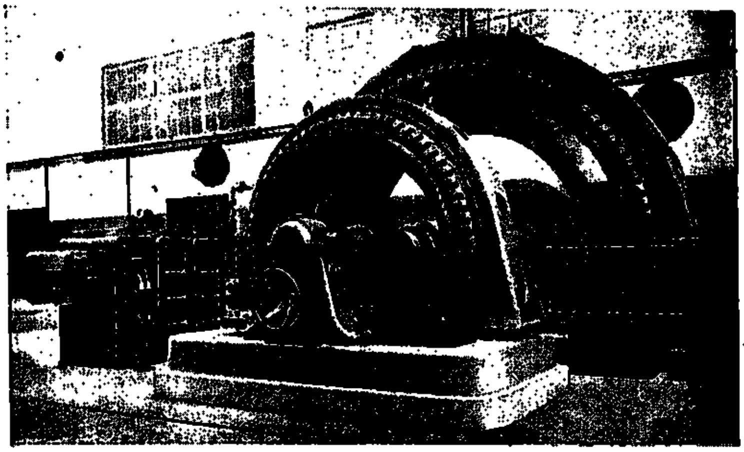


Fig. 5. 2,250 kVA synchronous motor with starting motor.

Generators, exciters, motor generator sets, switchgear, etc. have all been supplied by Asea. The plant was commenced during the latter part of 1920 and was completed about three years later. The station has since run without giving the slightest trouble.

In conjunction with the construction of the new power station, considerable alterations have been carried out in the various factories of Holmens Bruk. Three transformer substations are now located in different parts of the factory, and new distribution boards have been supplied for these transformers. For the substations, Asea has supplied among other plant two 2,000 kVA, 3,000/380 volt transformers, and two of 1,200 kVA, as well as a number of smaller ones.

Formerly, there were a number of turbines in the factory, driving various machines such as grinders etc. These have been removed and replaced by electric motors. The largest machine installed in this way is a synchronous motor, delivered by Asea at the beginning of 1924. This is designed for 2,250 kVA at 214 r.p.m., 50 cycles, 3,000 volts and $\cos\varphi = 0.8$, and is used to a considerable extent for power factor correction in connection with the works load which is chiefly made up of induction motors. As the starting torque required is high, it was not possible to make this motor self-starting as the surge of current, when switching on, would have been troublesome. On this account a direct connected starting induction motor for 600 h.p. at 245 r.p.m., 50 cycles, and 3,000 volts, furnished with combined starting and regulating resistance, has been used and the speed of this machine can easily be regulated for synchronising purposes. The synchronous motor is constructed on the usual principles. It is interesting to note that the bearings are provided with handpumps which provide forced oil lubrication during starting.*) In addition to the syn-

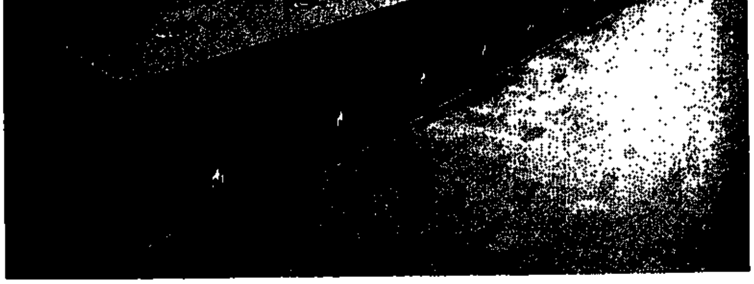


Fig. 6. Bench board for power station in control room.

*) Two similar motors, but of 2,900 kVA at 214 r.p.m., 50 cycles, 5,000 volts and $\cos\varphi = 0.8$ were also delivered by Asea to the Holmens Bruks & Fabriks A.-B's large factory at Hallstavik in Uppland, for which also a large number of transformers and motors etc. have been delivered for the new as well as the old installation.

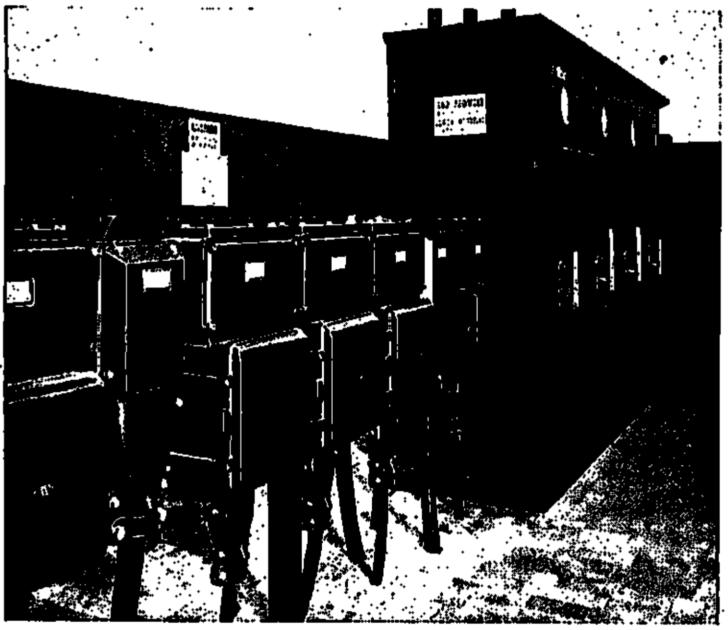


Fig. 7. Distribution board.

chronous motors a large number of induction motors have been delivered, the largest being of 2,400 h.p. at 210 r.p.m., 50 cycles and 3,000 volts, another one being for 1,000 h.p. at 210 r.p.m., 50 cycles and 3,000 volts. The former of the above, which has lately been supplied, is provided with six sliprings for Δ/Y-connection during starting and has brush lifting and short circuiting gear for the first three. In addition, it is provided with a separate phase advancer unit, so that it can be run at unity power factor at all loads from no load to full load. The phase advancer consists of a compensator for 17.5 kW at 960 r.p.m., 1 cycle, and 2,000 volts, driven by a direct connected three-phase induction motor of 32 h.p. at 50 cycles and 380 volts.

As mentioned in the foregoing, Holmens Bruk possessed a number of older power plants and of these some have been scrapped, some transferred elsewhere while some still remain in their original positions. For these various plants also, Asea has at different times delivered a large quantity of machinery and apparatus and this applies also to the general mill installation. As early as 1901 Asea supplied a three-phase generator of 200 kVA, 375 r.p.m., 50 cycles and 760 volts, which has now been reconnected for 380 volts. Three years later a 340 kVA Asea generator was delivered, running at 214 r.p.m. and wound for 50 cycles, 400 volts. Both these machines were designed for direct connection to water turbines. Later the mill installed a steam power station for which, in 1908, Asea supplied a small turbo generator of the double unit type, which is still in use, and later in 1911 a large turbo generator of 1,875 kVA running at 3,000 r.p.m. and wound for 50 cycles, 3,100 volts and power factor 0.8. The units of the small double generator were designed for 275 kVA at 750 r.p.m., 50 cycles and 400 volts. The two stators of this machine were constructed side by side and the two rotors were driven from a common gear, having three wheels, the two larger being connected to the parallel generator shafts and the third, which was considerably smaller, coupled to the shaft of the steam turbine. The gear was totally enclosed and designed to run in oil so that it was practically noiseless. These gears have proved to be very satisfactory predecessors of the present day precision gears, and made it possible to effect suitable connection between steam turbines and the electric generators during a period when it was not possible to build direct coupled machines, since steam turbines could not be designed to run

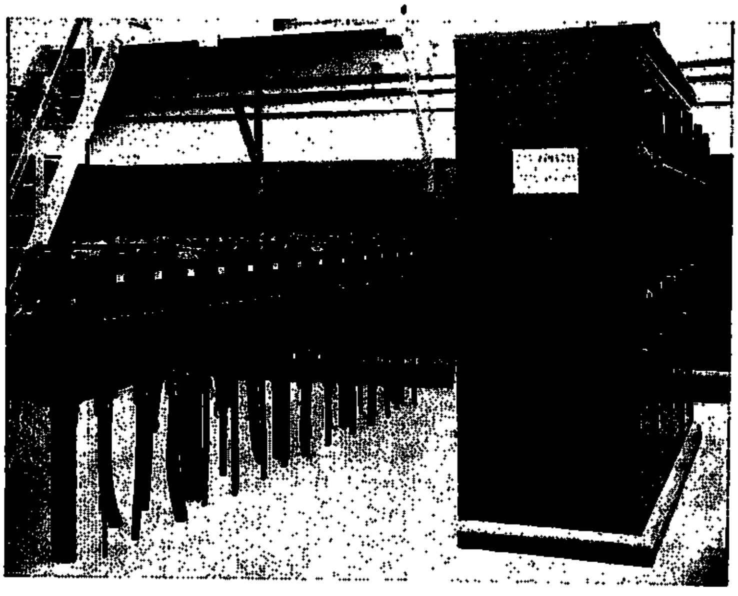


Fig. 8. Switch and distribution board.

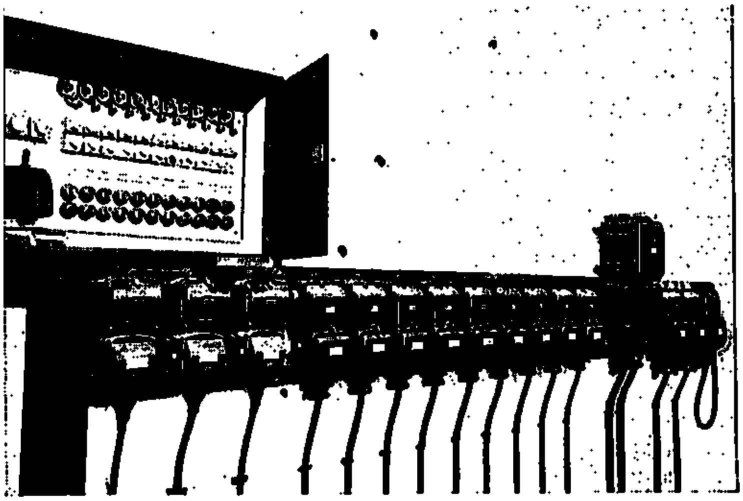


Fig. 9. Switchboard and distribution board.

sufficiently slowly, or electrical generators sufficiently fast. For several years after 1900 a large number of similar units were built for use in Sweden and abroad. Many of these sets are still operating perfectly.

It was not long, however, before steam turbines and alternating current generators were suitably constructed for direct coupling to one another. Asea took a very active part in this development and constructed several machines running at 3,000 r.p.m., which in their time constituted world records. The turbo generator which was delivered to Holmens Bruk was, however, by no means one of the largest. This machine was constructed with rotating field of cylindrical type, having radial slots, and otherwise was very similar to the turbo generator types which are constructed to-day.

The setting to work of the new power station has naturally made it necessary to introduce a change-over to purely electrical drive, not only in the Holmens Bruk but also among other consumers who were interested in the water rights. In a number of undertakings the whole installation has been brought up to date while in others, which were previously partially electrified, extensions have been put in hand so that use can be made of the electrical power available from the new station.

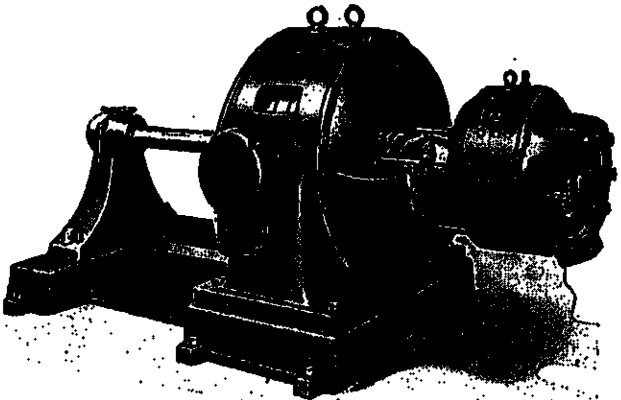


Fig. 10. 300 h.p. autosynchronous motor, 750 r.p.m., 50 cycles, 3,000 volts with exciter, cable box for armoured cable, extended shaft and third bearing.

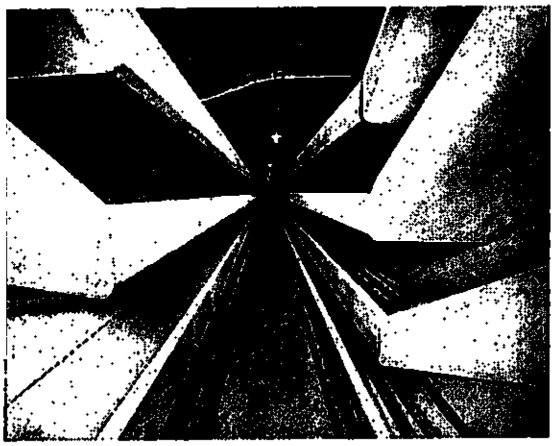


Fig. 11. Cable duct under power station.

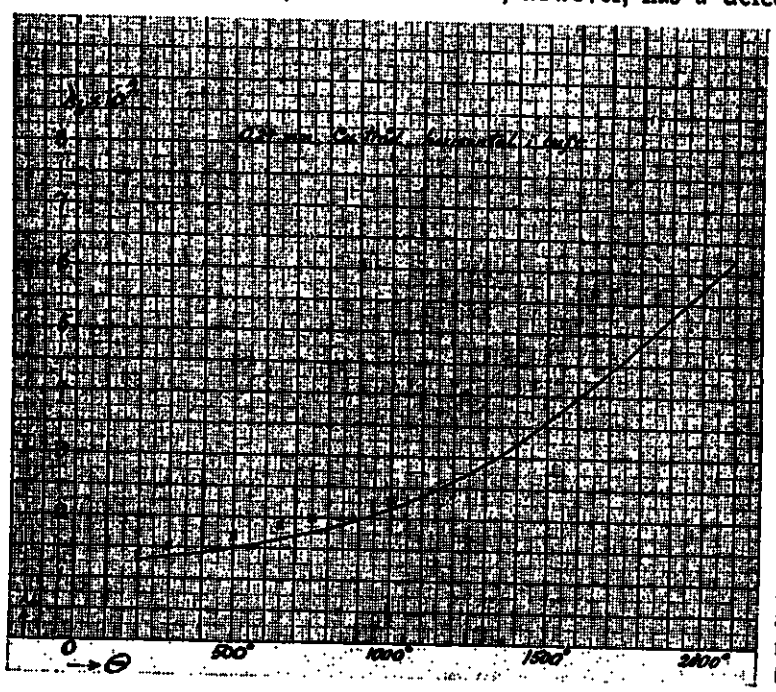
ARC FORMATION AND BREAKING CHARACTERISTICS OF SWITCHES.*

If two electrodes in air or some other gas, in contact with one another, and having a voltage E applied to them so that they are traversed by a current whose magnitude I_0 is determined by the circuit resistance R, are separated an arc is formed, provided both E and I_0 have values greater than certain critical values depending on the material of the electrodes. For ordinary metals (*e.g.* Au, Ag, Cu, Fe, Al, Z) the critical current is in general less than 0.5 amps. and the critical voltage approximately 10—25 volts.

If I_0 is below the critical value instead of an arc a spark may occur, if E is greater than a certain critical value depending on the surrounding gas. This critical value is in the neighbourhood of 300 volts for ordinary gases, (*e.g.* air, hydrogen, nitrogen).

The radical difference between an arc and a spark is that the flow of current through an arc depends to the greatest degree on the ionisation of the vaporized material of the electrodes, while in the case of a spark it depends chiefly on the ionisation of the gas surrounding the electrodes. An arc to a great degree exhibits the spectrum of the electrode material while a spark gives the spectrum of the surrounding gases.

The actual material of the arc is accordingly primarily determined by the material of the electrodes, and is practically speaking independent of the surrounding medium. Referred to our ordinary switches, this implies among other things that an arc between copper contacts, for example, has the same chemical composition both for airbreak switches and oil immersed switches. The difference lies in the fact that the chemical and physical characteristics of the outer layer of the arc are entirely unlike. At the same time, the geometrical dimensions of the arcs are greatly different.



0.31 mm Cu wire, horizontal in air.

Fig. 1. Specific cooling at different temperature rises, in air.

For the design of switches and for the determination of breaking capacity it is, of course, desirable to be able to calculate the geometrical and electrical dimensions of the arc. Mrs. Ayrton and other investigators established some time ago (about 1900) the equation:

$$e = a + \frac{b}{i} \quad \text{(1)}$$

In which e = the arc voltage,
i = the current,
$a = \alpha + \beta l$,
$b = \gamma + \delta l$,
l = length of arc,
$\alpha, \beta, \gamma, \delta$ = constants.

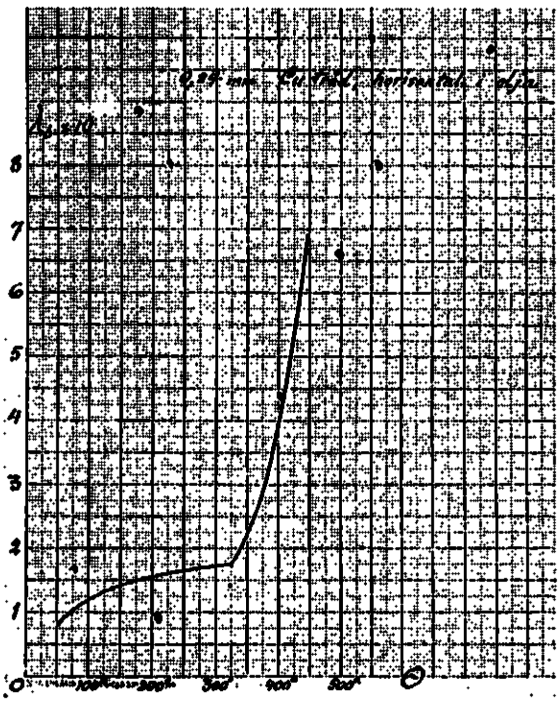
These equations were obtained empirically by investigating small arcs a few mm in length which were at that time used in arc lamps having open arcs. Later (1906) Steinmetz established the following formula for arc lamps with enclosed arcs (some cm in length):

$$e = a + \frac{b}{\sqrt{i}} \quad \text{(2)}$$

a = constant,
$b = \gamma + \delta l$.

The difference between these two formulae is not so important for arc lamps. Ayrton's formula, however, has a defect which makes it useless for long arcs, since it limits the energy dependent on the current exclusively to the surfaces of the electrodes and makes the energy in the open arc constant for a given length of arc and independent of the current. This is clearly incorrect.

In the very few investigations which have been published on arc formation as applied to switches, attempts have generally been made to employ Ayrton's formula, but naturally with



0.31 mm Cu wire, horizontal in oil.

Fig. 2. Specific cooling at different temperature rises in oil.

small success. At the same time, the formula of Steinmetz has not been referred to, although it would be expected that it should be more satisfactory.

Both equations have the same inherent fault — that the constants are only empirically determined, but their physical meaning has not been explained. At the same time, the conditions show that if we establish a heat or energy equation for an arc, based upon the law of equality between the energy supplied and given out, we must obtain an equation which is of the form given by Steinmetz. This has been carried out by the author and a description of results published in the I.V.A. Pamphlet, No. 44 "The Properties of the Electric Arc with respect to the Arcing of Circuit Breakers".

The static characteristic of the arc is determined in accordance with this investigation by the equation:

$$e_b = k_1 + k_2 \frac{l}{\sqrt{i}} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

$$\text{with } k_1 = 2\,\frac{\lambda_e}{\sigma_e}\,\frac{d\Theta}{dx}$$

$$\text{and } k_2 = 3.55\,\frac{\lambda_b\,\Theta}{\sqrt{\sigma_b}}$$

Where e_b = total arc voltage.

i = current in amps.

l = length of arc in cm.

Θ = temperature of arc above surroundings.

$\frac{d\Theta}{dx}$ = temperature drop at surface of electrode (at right-angles) per cm.

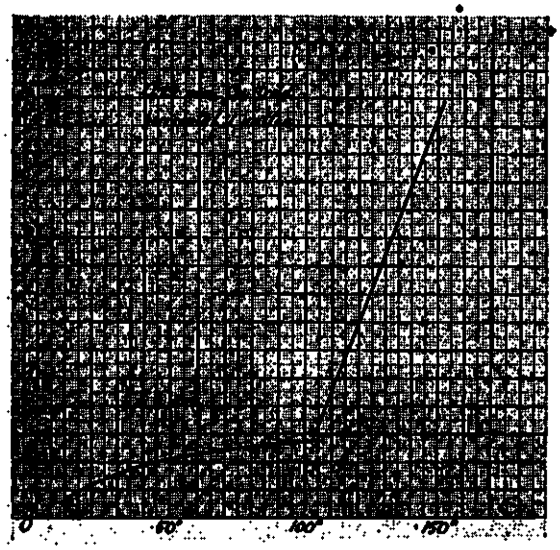
λ_e = coefficient of conduction of heat for the electrode material, watt/cm^2 for 1°/cm.

σ_e = current density at surface of electrode, amps./cm^2.

λ_b = loss of heat from arc to surroundings, watt/cm^2 for 1°.

σ_b = current density in arc, amps./cm^2.

As regards the discussion of this equation we refer to the paper mentioned above. We wish, however, to draw attention to two important assumptions beside those already given, namely that for a given electrode material the temperature of the arc is approximately constant and also the current density (both σ_e and σ_b) is constant which last implies that the cross sectional area of the arc varies automatically in proportion to the current. An arc is accordingly a conductor with variable cross section and constant density while a common metal wire is a conductor with constant cross section and variable current density. This also explains the so-called negative characteristic of an arc. The action of striking an arc consisting in the formation of an ionised or electrified gas is bound up with the transformation of the material of



0.31 mm Cu wire, horizontal in water.

Fig. 3. Specific cooling at different temperature rises in water.

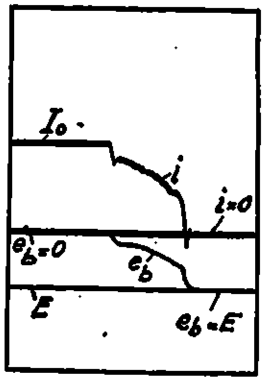


Fig. 4. Oscillogram: Break of non-inductive continuous current, air circuit breaker $E=110$, $I_0=3.0$.

the electrodes from one state of matter to another. The process accordingly constitutes in itself an automatic temperature regulator working within very close limits.

The two constants k_1 and k_2 are of great practical importance.

k_1 depends only on the electrode material (σ_e) and the heat conductivity of this material, (λ_e and $\frac{d\Theta}{dx}$). This relation is known to a great extent, particularly through the investigations of Professor Granqvist. In the electrical respect k_1 is a voltage = the sum of the voltage drops at the surfaces of the two electrodes. Strictly speaking k_1 is only a constant as long as $\frac{d\Theta}{dx}$ is constant, *i. e.* in the static condition.

k_2 is dependent both on the material of the electrode (σ_b and Θ) and on the cooling properties of the surrounding medium (λ_b). In the electrical respect k_2 is the voltage per cm of length of arc with a current of 1 amp.

The significance of the constant k_2 has never before been clearly expressed as far as the author knows.

Magnitude and significance of constants k_1 and k_2 for circuit breakers.

For circuit breakers it is in general an advantage for the length of the arc to be small. Accordingly both k_1 and k_2 should clearly be large.

For normal copper contacts the following approximate mean values apply, determined empirically by breaking tests:

For air break and oil break switches, $k_1 = 25$.
For air break switches, $k_2 = 50$.
For oil break switches, $k_2 = 5000$.

The great difference between air break and oil break switches is immediately apparent from the above. Under otherwise similar conditions the length of arc in air is in round figures 100 times greater than in oil (see equation 3). The reason for this lies chiefly in the greater cooling properties of oil expressed by the constant λ_b. The great dielectric strength of the oil is also of considerable importance in the case of alternating current but not in the case of continuous current. Since the constant λ_b has such a considerable influence it is of great interest to study its magnitude more closely for different materials, different temperatures and other factors affecting it.

For an arc in air it is possible to calculate λ_b directly with sufficient accuracy. Attempts have also been made by experiment to determine λ_b and good agreement has been found between the calculated and observed values up to the highest temperature used in testing, namely in the neighbourhood of 1,000°. It would, of course, not be justifiable to extrapolate from this temperature up to the temperature of the arc, about 2,100°. It is, however, possible by this means to determine the order of magnitude of λ_b with sufficient accuracy. The result is shown in fig. 1. The calculated values assume only cooling by convection and radiation but do not take into account cooling due to chemical reaction and are therefore too low. In the experiment in question electric current was passed through a free hanging horizontal copper wire, 0.24 mm in diameter, the voltage and current being measured. From this was obtained the power supplied and the resistance of the wire and thus also the temperature of the wire. Such a method gives good accuracy at the higher temperatures which are of special interest. If we assume that the chemical energy can reach, for example, 50 % of the above we obtain $\lambda_b = 0.1$ with an arc temperature of 2,100°. This value is approximately ten times greater than for low temperatures (up to about 100°) where the cool-

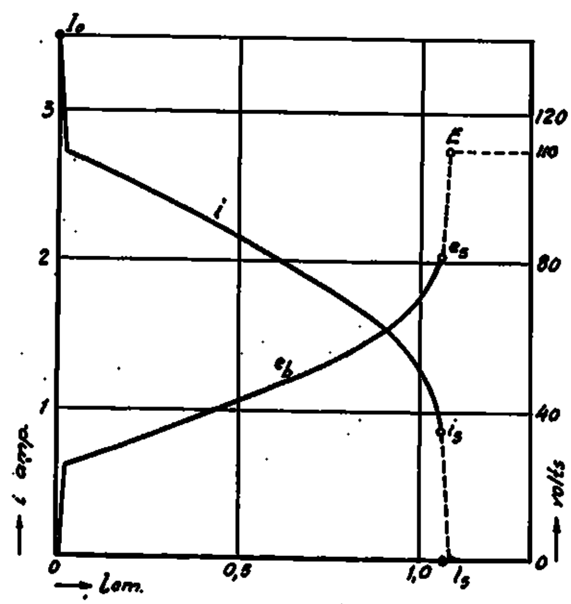


Fig. 5. Calculated curves for fig. 4, $k_1=25$, $k_2=50$.

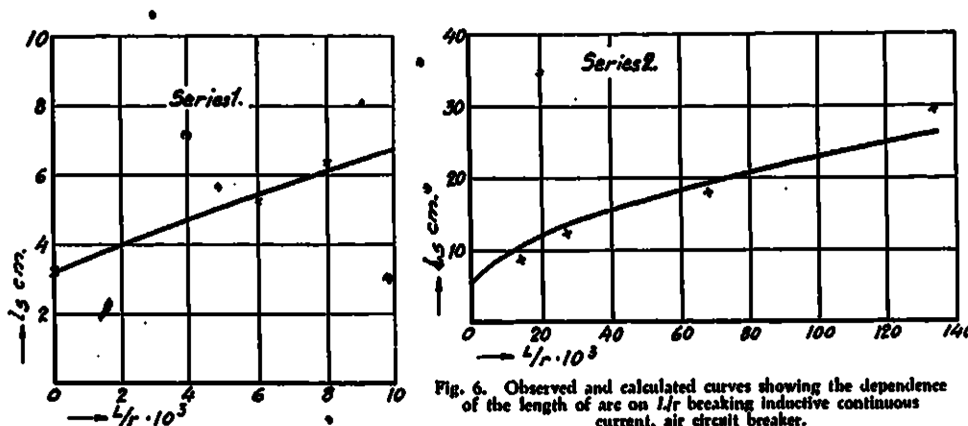


Fig. 6. Observed and calculated curves showing the dependence of the length of arc on L/r breaking inductive continuous current, air circuit breaker.
Series 1: $E = 230$, $I_0 = 4.0$, $v = 350$ cm/sec.
Series 2: $E = 440$, $I_0 = 3.0$, $v = 250$ cm/sec.

ing is determined chiefly by convection. The rapid increase in the cooling at high temperatures depends, as is well known, chiefly on the radiation.

When cooling in a liquid the specific loss of heat from the wire similarly increases very quickly with the temperature, namely as soon as this exceeds the boiling point of the liquid where the heat of vaporisation becomes effective. In tests on the heating of a copper wire in oil in the same manner as described above, the values given in fig. 2 have been obtained. Unfortunately, the test does not go beyond a temperature of about 500° so that extrapolation to 2,000° is very uncertain. At the same time it is sufficiently clear that $\lambda_b = 10$—20 *i.e.* at least one hundred times greater than in air. To calculate λ_b more directly for oil would give rise to considerable difficulties.

In this connection it should be remembered that oil is not the only liquid which can be used for circuit breakers. Experiments have, for example, been made with carbon tetrachloride which exhibits some characteristics worthy of note (boiling point = 76°, freezing point = —24°). We have also carried out some experiments using ordinary water which show (fig. 3) that λ_b at a little over 100° is about ten times greater than for oil. On account of this it would appear that water should be the more suitable liquid to employ for circuit breakers. This also is actually the case to the extent that we can secure immunity from other unfortunate qualities *e.g.* that water is not an insulator but a conductor.

The constant k_2 depends further on the current density σ_b. It might be possible to calculate σ_b by the help of the theories which exist for conduction of electricity through gases. We have, however, so far been satisfied with measuring the dimensions of the arc by the photographic method, and this gives a value of σ_b which agrees well with the value calculated from break tests.

The dynamic characteristic of the arc.

For the calculation of the arc for circuit breakers it is, of course, the dynamic and not the static characteristics which must be used. During break e_b, i and l all vary. If we take this into account we find that a further quantity is introduced into the arc equation (3) which is due to the effect of the heat capacity. In this way, for example, we obtain with certain assumptions with constant l but variable e_b and i:

$$e_b = k_1 + k_2 \frac{l}{\sqrt{i}} + k_3 \frac{l}{i} \frac{di}{dt} \quad \ldots\ldots\ldots (4)$$

$$k_3 = \frac{4.2\, T c_p\, \gamma}{\sigma_b}$$

T = temperature
c_p = specific heat
γ = specific weight
of the gas in the arc.

The new term takes the form of an inductive voltage and its influence is to a great degree to oppose rapid alterations in the current, and thus to increase the breaking time and the length of the arc. Experiment shows, however, that in the case of copper electrodes this action is very inconsiderable. Certainly for oil-immersed circuit breakers the last term in equation (4) becomes vanishingly small in comparison with the last term but one.

Although the influence of the heat capacity is of great importance in certain cases, *e.g.* during the unstable period of the arc, with alternating current of exceedingly high frequency *etc.*,

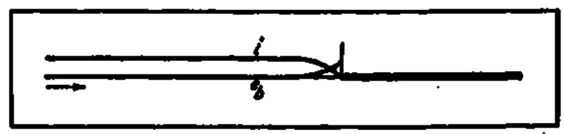
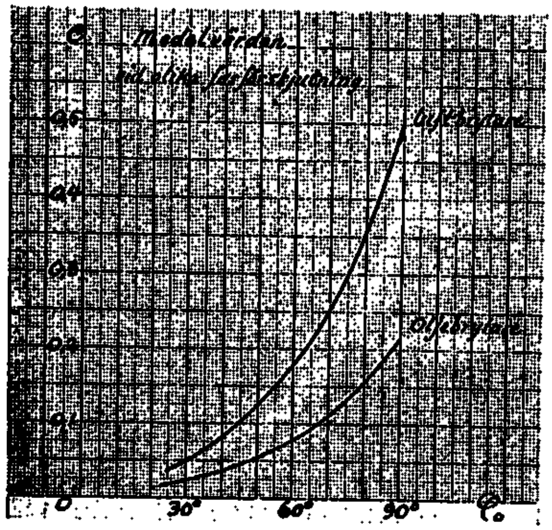


Fig. 7. Oscillogram: Break of inductive continuous current, oil immersed breaker, $E = 4$, $I_0 = 20$, $L/r = 1.25$, $e_b = 1{,}600$ (max.).

we can, however, neglect it in the case of a preliminary investigation of breaking action for ordinary commercial circuit breakers.

In the following, accordingly, we shall work with equation (3).



Mean values with various phase angles.
Luftbrytare = Air circuit breaker. *Oljebrytare = Oil circuit breaker.*

Fig. 8. Curves showing the dependence of the constant c and thus the lenght of arc on the phase angle when breaking alternating current.

Length of arc.

For a circuit breaker the final length of the arc is a factor of overwhelming importance. If we wish to break quickly, which is the general rule and in any case so quickly that the self extending tendency of the arc itself has not time to be effective, the distance of break should be equal to or greater than the length of arc. Otherwise the breaking time is increased and in this way considerable disadvantages can arise by reason of the increased development of heat.

This holds good for the case where the arc is drawn out only by the receding of the switch contacts from one another. If, however, we use some kind of artificial "blow-out" the conditions are different. The distance of break can then be less than the length of arc, but the space for the arc to develop to its full length in a certain direction must always exist.

As the equation of the arc is known it can be introduced into the complete equation for any circuit whatever and in this way it is possible for us to study the break more closely, and to calculate the maximum length of the arc l_s.

In the paper already referred to such calculations have been made for some common simple circuits, and we shall accordingly confine ourselves to a brief reference to the results.

For the sake of simplicity we shall make the assumption already mentioned, that the influence of the heat capacity can be neglected and thus that equation (3) applies, while at the same time the voltage is so high that k_1 can be neglected. The cases in which these assumptions cannot be allowed are handled as special cases. The arc voltage then becomes:

$$e_b = k_2 \frac{l}{\sqrt{i}}$$

I. *Length of arc on breaking simple D.C. circuit.*

The equation of the circuit:

$$E = ir + L\frac{di}{dt} + k_1 l + k_2 \frac{l}{\sqrt{i}} + k_3 \frac{l}{i}\frac{di}{dt}$$

If k_1 and $k_3 = 0$

$$\therefore E = ir + L\frac{di}{dt} + k_2 \frac{l}{\sqrt{i}} \quad \ldots\ldots\ldots\ldots (5)$$

a) for $L = 0$ we obtain:

$$l_s = \frac{0.38}{k_2} E\sqrt{I_0} \quad \ldots\ldots\ldots\ldots (6)$$

$$e_s = 0.67\ E$$

$$i_s = 0.33\ I_0$$

b) for $L > 0$ we obtain:

$$l_s = 0.5\, l_0 + \sqrt{(0.5\, l_0)^2 + \frac{2\nu l_0 L}{r}} \quad \ldots\ldots\ldots\ldots (7)$$

$$\text{where } l_0 = \frac{0.38}{k_2} E\sqrt{I_0}\ (= l_s \text{ vid } L = 0)$$

l_s = length of arc, when unstable, cm.
i_s = current, „ „ amps.
e_s = arc voltage, „ „ volts.
I_0 = current at commencement, amps.
ν = speed of break, (constant), cm/sec.

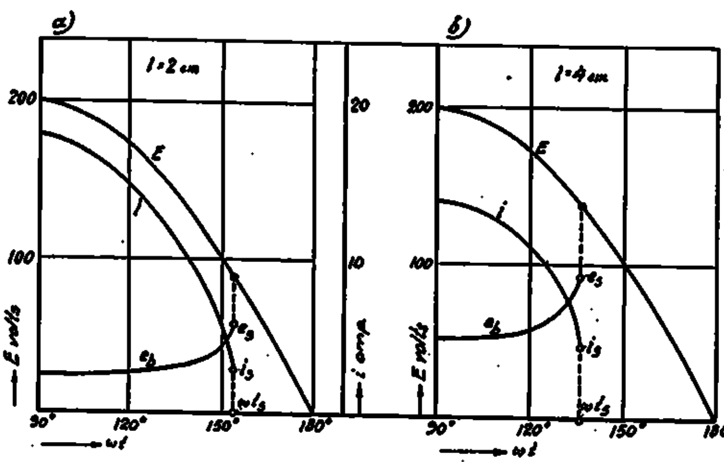


Fig. 9. Calculated curves showing current and arc voltage e_b during a quarter period with generator voltage E of sine form, non-inductive circuit and two different lengths of arc.

Fig. 4 shows a typical oscillogram for a continuous current break in a noninductive circuit. The pressure of the circuit is in this case low, (110 volts), so that k_1 applies. The calculation of the same curves in accordance with equation (5) wherein E is substituted by $(E-k_1)$ and I_0 by $\frac{E-k_1}{r}$ and the speed of break is assumed constant, gives as a result the curves in fig. 5. An example of the application of equation (6) for an inductive continuous current circuit is shown in fig. 6, which gives the length of arc dependent on the time constant L/r with otherwise constant conditions. The break action with an inductive circuit is characterised by the fact that the length of arc increases with the time constant and the speed of break. The voltage generated with an inductive break is also of particular interest as, during the last instant of unstable extinction of the arc, it can reach a considerable value. An example of this is shown in fig. 7.

II. *Length of arc on breaking simple A.C. circuit.*

The equation of the circuit is:

$$E = E_m \sin \omega t = ir + L\frac{di}{dt} + k_1 + k_2\frac{l}{\sqrt{i}} + \frac{k_3 l}{i}\frac{di}{dt}$$

If k_1 and $k_3 = 0$

$$E_m \sin \omega t = ir + L\frac{di}{dt} + k_2\frac{l}{\sqrt{i}} \quad \text{........ (8)}$$

From which we obtain:

$$l_s = \frac{c}{k_2} E\sqrt{I_0} \quad \text{.............. (9)}$$

c is here a constant depending on the phase angle (φ_0) at the commencement of the break, on the speed and on the cooling and insulating properties of the surrounding medium during the zero period of the current.

For an approximate calculation of the length of arc for normal circuit breakers c can be taken from the curves (fig. 8), and we can assume:

$k_2 =$ 100 for air circuit breakers,

$k_2 =$ 5,000 for oil immersed circuit breakers.

These values apply as approximate mean values for ordinary circuit breakers of modern construction, employing no artifical method of quenching. Thus, for example, the air break switches in question include ordinary knife switches and isolating switches, hand operated without quick break contacts, the arc being drawn out chiefly in a horizontal direction. The oil switches include circuit breakers of ordinary type, the arc being drawn vertically downwards.

The constant c is determined by the possibility of the re-ignition of the arc. Its numerical value is easily influenced, *e.g.* in the case of air break switches by a very slight draught of air, which would not affect k_2 to any considerable extent.

From the breaking point of view it is most simple to regard an alternating current as a continuous current which dies out of itself at

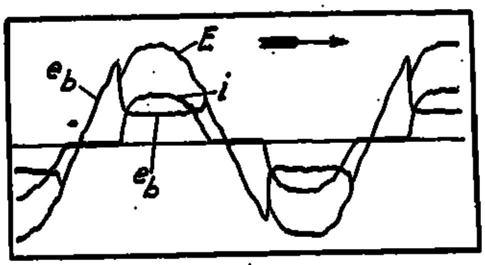


Fig. 10. Oscillogram: Arc lamp, carbon electrodes, non inductive circuit.

the conclusion of each half period, rising again during the next half period on the assumption that the conditions for re-ignition are fulfilled. The calculated process in a noninductive circuit is shown in fig. 9 which gives the form of the current and voltage curves at the conclusion of a half period. The oscillogram fig. 10 bears out the calculated values. Calculated curves of voltage and current when breaking an inductive circuit are given by fig. 11 which is in turn borne out by the oscillogram fig. 12. In the case of air break switches, the form of the arc voltage curve is often affected by the thermal capacity (rapid changes in the curve are eliminated) as shown e.g. in fig. 13.

From the above it appears that it is theoretically possible to break any alternating current in a time approximating to a half period. This possibility is made use of in practice as far as may be. On the other hand the half period must be regarded as the shortest possible breaking time for ordinary switches. (We may remark here that the necessary distance for the break can never be less than the flash-over distance for the highest voltage occuring between the electrodes.)

There are a large number of readings available from different sources which we have made use of to check the formulae given above for length of arc. The agreement between observed and calculated values has been found in general exceedingly good.

It is of great value to the designer to be able to calculate the length of arc. Particularly, however, in the case of air break switches, such

as knife switches, isolating switches *etc.* this is often important also to the users of the apparatus, so as to enable them to judge the breaking capacity. In this way many short circuits can be prevented.

A comparison between the length of the arc when breaking the same amount of power on various kinds of circuit shows:

1) The arc is longer in the case of D.C. than in the case of A.C.

2) It is longer for inductive D.C. circuits than for non-inductive circuits depending on the inductance and speed of break.

3) In the case of inductive A.C. circuits ($\cos\varphi = 0.1$) it is, in air break switches, approximately the same length as for non-inductive D.C. circuits.

4) In the case of non-inductive A.C. circuits it is considerably shorter than for non-inductive D.C. circuits.

Time of break.

As the length of arc is known, the time of break can easily be calculated if the speed of break is known. The breaking time is of greatest importance in connection with calculations regarding the power in the arc.

Energy in the arc.

It is naturally important to be able to determine the heat developed during the period of break, having regard to the heat at the electrode surfaces (burning the contacts) as well as to the heat in the arc proper (causing formation of gas in oil switches).

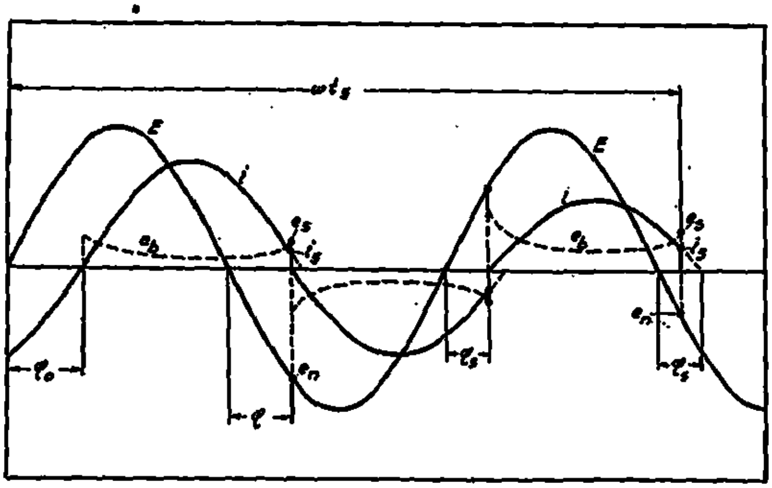


Fig. 11. Theoretical curves, break of inductive alternating current, immediate re-ignition (oil switch). Re-ignition voltage e_n depending on the phase angle (φ_0).

1) *Energy at electrode surfaces.*

If we assume the voltage drop at the surface of the electrodes to be a constant k_1, the energy is obtained by

$$W_e = \int_0^{t_s} k_1\, i\, dt.$$

The connection between i and dt is obtained from the circuit equation. Thus, for example, for v = constant we obtain:

a) for non-inductive D.C. circuit, equation (5),

$$W_e = \frac{0.29}{v}\,\frac{k_1}{k_2}\,E\,I_0^{1.4} = 0.76\,k_1\,I_0\,t_s \;\ldots\ldots\ldots \quad (10)$$

b) For inductive A.C. circuit, equation (8),

$$W_e = \frac{0.9\,c}{v}\,\frac{k_1}{k_2}\,E\,I_0^{1.4} = 0.9\,k_1\,I_0\,t_s \ldots \quad (11)$$

W_e gives here the sum of the energy at the surfaces of the two electrodes.

2) *Energy in the arc.*

$$W_b = \int_0^{t_s} e_b\, i\, dt$$

If we assume v = constant and for e_b make use of the expression $e_b = \frac{k_2\, l}{\sqrt{i}}$ and further determine the connection between i and t in accordance with the equation applying for the circuit, we obtain for example:

a) For non-inductive D.C., equations (5) and (6),

$$W_b = \frac{0.08}{k_2\, v}\,E^2\,I_0^{1.6} = 0.21\,E\,I_0\,t_s \ldots \quad (12)$$

b) For inductive D.C., equations (5) and (7), with large inductance (*e.g.* $\frac{L}{r} > 0.1$) and speed of break 100 cm/sec. or more.

$$W_b = 0.2\,\frac{L}{r}\,E\,I_0 \;\ldots\ldots\ldots \quad (13)$$

and accordingly independent of t_s.

c) For inductive A.C., equation (9), with a phase angle of 90°: with air break switches,

$$W_b = \frac{0.178}{k_2\, v}\,E^2\,I_0^{1.6} = 0.28\,E\,I_0\,t_s \quad (14)$$

With oil switches, for $c = 0.22$

$$W_b = \frac{0.022}{k_2\, v}\,E^2\,I_0^{1.6} = 0.1\,E\,I_0\,t_s \quad (15)$$

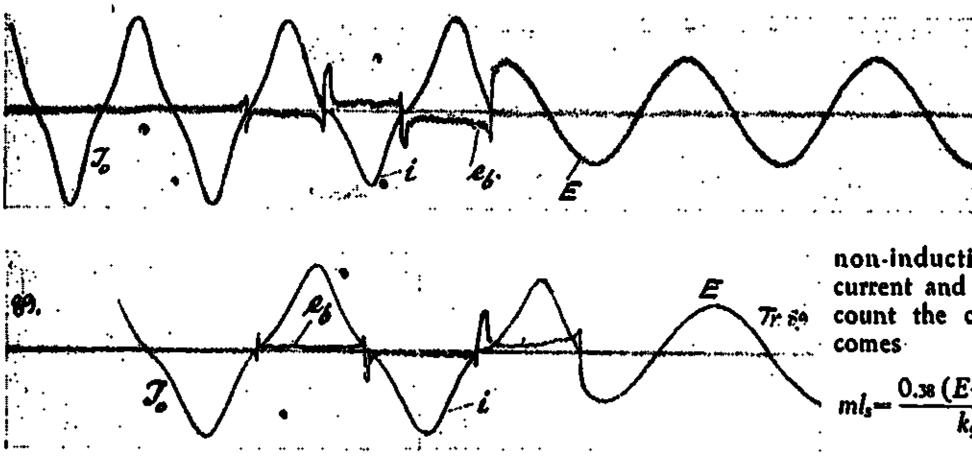


Fig. 12. Oscillogram: Break of short circuited generator with oil switch, low breaking speed. $E = 6{,}000$ volts, $I_0 = 1{,}400$, effective values.

Regarding these examples of calculated results we wish to point out particularly that they are in extremely good agreement with values found empirically. Thus Bauer for ordinary knife switches and non-inductive D.C. gives $W_b = 0.18 \cdot E\ I_0\ t_s$ (compare equation 12). For alternating current and oil immersed switches (compare equation 15) Bauer gives the constant 0.02 for nearly non-inductive circuits and 0.07 for a short circuited generator circuit. Brühlmann gives for a short circuited generator a minimum of 0.07, but considers that this value in the case of large outputs may be increased up to 0.2.

Both Bauer and Brühlmann have further established by observation that the amount of gas formed in oil switches is proportional to the breaking work W_b. This fact represents a further confirmation of the assumptions we have made regarding constant temperature, specific cooling of the arc and current density.

Various methods of reducing length of arc, breaking time and breaking work.

Several breaks in series.

A very commonly employed way of reducing the length of arc is to arrange a circuit breaker with two or more breaks in series. If the number of breaks $= m$, then in the case of high voltages the approximate length of each arc is $1/m$ of the total arc length. From the constructional point of view this gives rise to various indirect advantages such as increased speed of break, better utilisation of the space at our disposal in the oil tank, better control of the movement of the arc, *etc.* If the voltage is low, or if the number of breaks is very large, we can bring about a considerable reduction in the total arc length and indeed theoretically it may be reduced to zero. This will be apparent from the complete formula which, in the case of non-inductive continuous current and taking into account the constant k_1, becomes

$$ml_s = \frac{0.38\,(E-mk_1)}{k_2}\sqrt{\frac{E-mk_1}{r}} \qquad (16)$$

If $mk_1 \geqq E$, the total arc length $ml_s = 0$.

In the case of non-inductive alternating current this method is also effective. In the case of an inductive circuit, however, it may, like increasing the speed of break, be in the nature of a two edged sword, as will be clear from the following example of the calculation for an inductive D.C. circuit.

If the total arc voltage e_b is assumed to increase with the time t from 0 up to mk_1 we can in this case put

$$e_b = k \cdot mv_1\ t = at \leqq mk_1$$

$a =$ constant

$k =$ constant $=$ voltage per cm of length of break $\left(\approx \frac{k_1}{0.1} = 250\right)$

$v_1 =$ linear breaking speed

$v = mv_1 =$ total effective speed of break

The equation of the circuit:

$$E = ir + L\frac{di}{dt} + at \qquad (17)$$

from which we obtain

$$t_s = \frac{E}{a} + \frac{L}{r}\left(1 - e^{-\frac{r}{L}t_s}\right) \qquad (18)$$

If, for example, we have the requirement that with constant E and I_0 the time of break t_s is to be constant $= 0.01$ although $\frac{L}{r}$ increases, m must be increased in the ratio given in the following table, under the assumption that v_1 is maintained unchanged.

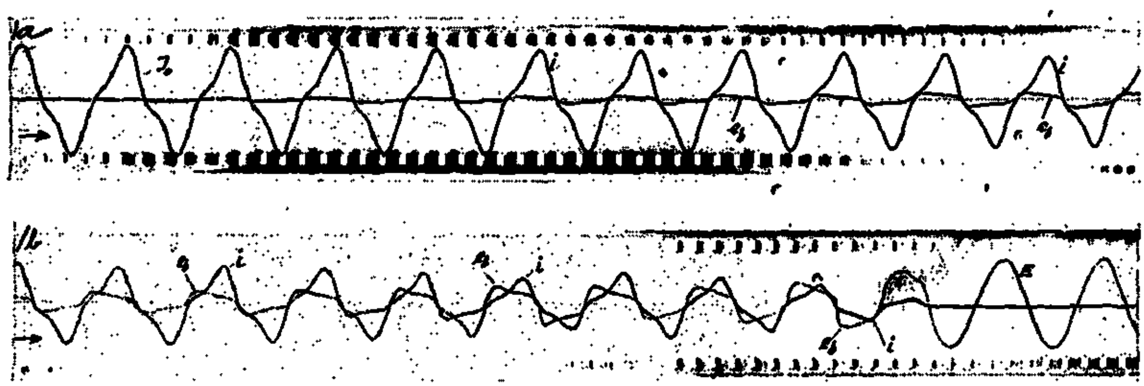


Fig. 13. Oscillogram: Break of single-phase transformer circuit at no-load with air circuit breaker, $E = 3{,}000$, $I_0 = 5$, effective values.

$\frac{L}{r}$	m
0	1
0.002	1.25
0.01	2.7
0.05	10
0.1	20
0.5	100

From the above it will be seen that the method of employing a number of breaks in series may give rise to considerable difficulties with higher values of L/r.

Increased cooling.

By directing a stream of air or oil against the arc the constant k_2 may be increased. This may be regarded as a good method, with the exception of the case of inductive continuous current, where it must be ensured that the advantage gained is not taken away by increased breaking speed, due to the "blowing out" action.

In the case of alternating current cooling by a draught of air or stream of oil is particularly effective when the current is zero and by this means the constant c may well be considerably reduced.

Such a method has often been used with advantage in practice. For example, expulsion chambers in the case of oil immersed circuit breakers are a particularly simple and effective arrangement of this kind and have the valuable characteristic of more powerful action as the current becomes greater. (On the other hand when the current is low the action of expulsion chambers of the construction now common is practically reduced to nothing).

Speed of break.

With non-inductive continuous current the length of arc is not affected by the speed of break but the breaking work is inversely proportional to the speed of break and it is accordingly to be recommended that this should be made high. (See equation 6 and 12).

With inductive continuous current the length of arc increases with the speed of break and in the case of high inductance is proportional to the square root of the breaking speed. The breaking work is affected slightly or not at all by the breaking speed. It is accordingly not advantageous to have this high. The fact that in spite of this a high breaking speed is often used is because we require a short breaking time for other reasons, *e.g.* to reduce the damage which might be caused by a short circuit of long duration (flash-over at a commutator). With high inductance the breaking time is inversely proportional to the square root of the breaking speed. (See equations 7 and 13). By increasing the speed of break the breaking time is reduced in the same proportion as the length of arc is increased.

With non-inductive alternating current or where the inductance is inconsiderable a high breaking speed is undoubtedly advantageous since the constant c is so affected that both length of arc and breaking work is reduced. With high inductance care must be used even in the case of alternating current. The effect of increase is, as it were, to raise the self-induction of the circuit whereby both the length of arc and breaking work is increased. It can be shown that for a certain current the breaking speed affects $\frac{di}{dt}$ by about the same percentage if it is proportional to the working voltage. It accordingly follows from this that to a great extent a higher speed of break is permissible and to be recommended in the case of high working voltages. Inversely also, if the voltage is low, so-called instantaneous break is less suitable in the case of inductive alternating

current, as well as in the case of inductive continuous current.

Magnetic blow-out.

A magnetic blow-out acts in an entirely different manner from ordinary blowing. Magnetic blow-out should be regarded as a method of obtaining a high breaking speed without the necessity of a rapid increase in the breaking distance between the electrodes. On this account the remarks made above with regard to breaking speed apply here also to a great extent.

From ordinary observations on air break switches we might be led to think that magnetic blow-out gives rise to decrease in the length of the arc. This is, however, a mistake or rather an illusion and is due to the fact that the duration of the arc is so short that the eye is unable to follow its development. This has been demonstrated in experiments made by Eschholz who by photographing the arc with a special camera has shown that the length of arc is practically speaking unaltered. Up to an effective breaking speed of $v = 6{,}000$ cm/sec. the decrease in the length of arc was so small (10 to 15 %) that it cannot be ascribed with certainty to the magnetic blow-out. At the same time, however, a considerable decrease in the time of break is obtainable in this way.

Conclusion.

The object of this short treatment of arc formation in the case of circuit breakers has been to show that we are able, at the present time, to calculate the electrical and geometrical dimensions of the arc within very close limits, and under all conditions with an accuracy at least equal to that with which we have to be satisfied in the solution of technical problems in general. That the formulae made use of are not only empirical but have a wide applicability in that the terms composing them have a real physical meaning is made clear, and this should be of particular value.

The electrical side of the circuit breaker problem is, practically speaking, solved. The problems which can still give rise to certain difficulties are the mechanical construction of the breakers and their design for different local conditions (erection and operation) and above all the important question of adequate maintenance of automatic switchgear. *Sven Norberg.*

ALIGNMENT OF MACHINES.

The aligning of machines is a delicate piece of work, and should preferably be carried out by skilled machine erectors. Even so, however, it often happens that erection is not carried out in the way we would recommend, and for this reason we are submitting herewith a few instructions for this kind of work. They cover briefly the method which in our opinion should be followed to attain, with the least possible trouble, a correct and true alignment, but they do not by any means give full instructions for the complete machine erection work.

Alignment of couplings.

a) *Rigid couplings, flexible bolt couplings, movable pin couplings of Stal manufacture.* Place a spacer "a" between the coupling halves at the periphery as shown in fig. 1. Press the shafts together so as to hold the spacer in its position. Measure the distance "x" diametrically opposite to the spacer with the shaft in its original position, and also after having turned the shaft through 90°, 180° and 270°, (four measurements in all).

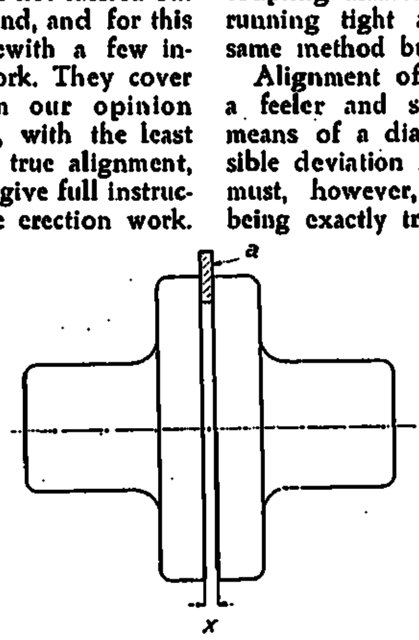


Fig. 1.

The difference between the largest and smallest value of "x" should not exceed 1/2,000 of the coupling diameter. If the coupling halves are running tight against each other, employ the same method but without using any spacer.

Alignment of the shaft centres is made by a feeler and straightedge, or still better by means of a dial indicator. The largest permissible deviation is 0.05 mm (0.002"). Due regard must, however, be taken to the flanges not being exactly true or being eccentric.

b) *Leather block or leather strap couplings.* It is usually immaterial which half of a leather-block coupling is placed on the driving or the driven shaft, unless the general arrangement determines the procedure.

The coupling is put on as shown in fig. 2. Last of all, the leather-blocks should be inserted and secured by steel wire springs, preventing them from coming out. These blocks, which should fit the openings

as closely as possible, are to be marked with the same number as their corresponding openings, and should in case of dismantling always be put back in the same positions.

When erecting, the alignment of the shaft centres should be checked in the following manner: —

Draw a radial chalk line on both the halves at "A" and "B", when placed in position (I), as per fig. 2. Measure the radial air gap between

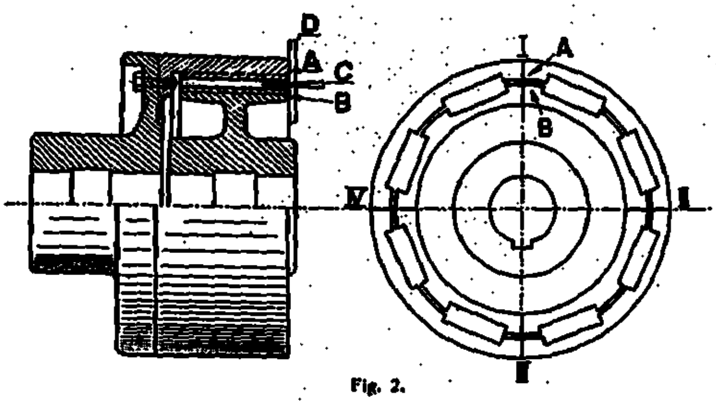


Fig. 2.

the halves by the aid of a wedge-shaped airgap gauge. Place a straight edge against the surfaces "A" and "B" and check the axial displacement by a feeler between the halves. Both these measurements are to be made to 0.1 of a millimetre (0.004").

Turn both halves 90°, *i.e.* to position (II), and repeat the above measurements, after having drawn a chalk line at the place of measurement.

The same procedure is further applied in Positions (III), (IV), and (I) and should after adjustment be repeated until the measurements in all positions agree with a maximum tolerance of 0.05 mm.

A leather strap coupling is aligned in the same manner. If the inner half is located on the motor shaft, the outer half protects the strap from being thrown out on a breakage of the strap occurring. After alignment, the strap should be threaded in and locked.

Alignment of direct connected machines with end shield bearings on foundation studs.

Screw the foundation studs into the stator feet and insert the dowel pins in their reamered holes. In order to make the foundation studs fit, the erection should be carried out after having marked the studs as well as the stator feet.

Place the machine on the foundation, and align the coupling in accordance with the foregoing instructions, and check by a spirit-level that the shaft of the machine, unless specially made to work in another position, is horizontal. For adjustment of the stator use shims of iron or any other hard metal underneath the foundation studs.

After checking that the alignment of the coupling is exactly as set out in these instructions, the foundation studs should be cemented in, using a fine grade of cement.

Machines mounted on slide rails.

Screw the slide rails tight on to the machine and place it on the foundation. With belt or rope drive, ascertain that the middle point of the belt or rope pulley agrees with that of the driven pulley and that the shafts of the driving and driven machines are parallel. With gear drive, make the alignment in the same way as set out above, but ascertain further that the gears engage satisfactorily on both the extreme positions. Check that the upper surfaces of the slide rails are level in the longitudinal direction. Their position in the transverse direction will be determined by the location of the driven shaft.

After having checked that the alignment has been properly carried out according to these instructions, the foundation bolts and slide rails are to be cemented in, using a fine grade of cement.

Small motor generators with common bedplate.

Small motor generator sets do not need to be taken off the bedplate in order to align them, as the bedplate can be levelled on the foundation by putting shims underneath it.

For this reason, two machined surfaces on the upper side of the bedplate at right angles to each other, have been extended 10 mm each, so that a reliable position for the spirit level can be found. After having levelled the bedplate in this manner and ascertained that the coupling runs true as indicated above in the chapter "Alignment of couplings", it should be cemented in together with the foundation bolts, employing a fine grade of cement, and filling up inside to half the height of the bedplate.

Larger motor generator sets on common bedplate.

If the motor generator is delivered erected on the bedplate, the set must first be dismantled. Place the bedplate on the foundation, cement in the foundation bolts unless this has been done already, and locate the bedplate horizontally by putting shims underneath wherever required. All machined surfaces must be checked to see that they are in the same (or in parallel) planes. Due to released stresses caused by the casting, it may be possible that the shape of the bedplate has altered during transport, and therefore it may prove necessary temporarily to

employ the foundation bolts for forcing the bedplate back into its proper shape.

After having aligned the bedplate and supported it by shims, so that no deformation due to the weight of the machines to be placed on it, can take place, put the machines on the bed, tighten all bolts of the stator and bearings, and insert the dowel pins. Check the air gap and the axial play in the bearings before grouting in the bedplate with a fine grade of cement up to a height of about 50 mm. Afterwards, pour concrete into the remaining free space in the bedplate.

If the set is of such a size that the bedplate is packed separately, the same method of erection should be employed. Should the bedplate be split, the machines are to be aligned on the previously aligned bedplate, and holes for the dowel pins drilled and reamered before grouting with cement and filling with concrete as described above.

Machines on separate bedplates or with one bearing and stator on a common bedplate.

Locate the bedplate or plates on the foundation by using a spirit level and taking measurements from the shaft of the machine to which the machine under erection is to be coupled. Afterwards, put the machine on the bedplate or plates and bolt both the flanges together. If necessary, adjust the plate or plates so as to give adequate endplay in the bearing, after this latter has been screwed on to the bedplate. The alignment of the rotor should then be checked by different methods, which depend upon the number of bearings, and the size of the machine.

a) *One bearing and shaft with flange couplings, arrangement 130.* Smaller machines are erected complete with their outboard bearings; the bolts of the flange coupling are loosely screwed up, so that the shaft end will rest on the guide flange. Ascertain in the manner described under rigid couplings, with feeler between both the halves, that these are parallel, otherwise make the necessary adjustments by altering the location of the outboard bearing until the correct position of the flange has been obtained.

On larger machines, do not put on the upper half of the bearing. Put a spirit level on the shaft in the bearing, and turn the rotor slowly. If the rotor is correctly aligned, the reading of the spirit level should be equal in all positions of the shaft. Should it not be so, adjustments of the location of the bearing are to be made until this equal reading is obtained.

When it has been ascertained that the rotor is aligned, screw the bearings on to the bedplate and insert the dowel pins after de corresponding holes have been reamed. Then align the stator in such a manner that the stator and rotor are parallel and the air gap is equal on both sides of the shaft in a horizontal level and about 10 % greater below the rotor than above. Tighten the stator bolts, insert the dowel pins and grout the bedplate or plates with cement and fill with concrete as previously described.

b) *Several bearings, shaft with flange or flexible coupling.* Alignment of machines with common shaft is to be effected in accordance with the instructions given for a motor generator.

On machines with two bearings each, align the couplings, whether rigid or flexible, as stated above. For machines of other arrangements apply the instructions given herein for a corresponding arrangement.

After the machines have been aligned and grouted in, the bearing surfaces of the shafts must be smeared with marking colour and the bearings scraped to bed the shaft down properly in order to ensure a good bearing surface. On the side of the lower bearing half, where the shaft is turning downwards, the bearing metal must be scraped out from the oil ring groove so that the oil will be distributed along the whole length of the bearing.

Vesterås 1927, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

ALLMÄNNA SVENSKA ELEKTRISKA A.B.
VESTERÅS — SWEDEN

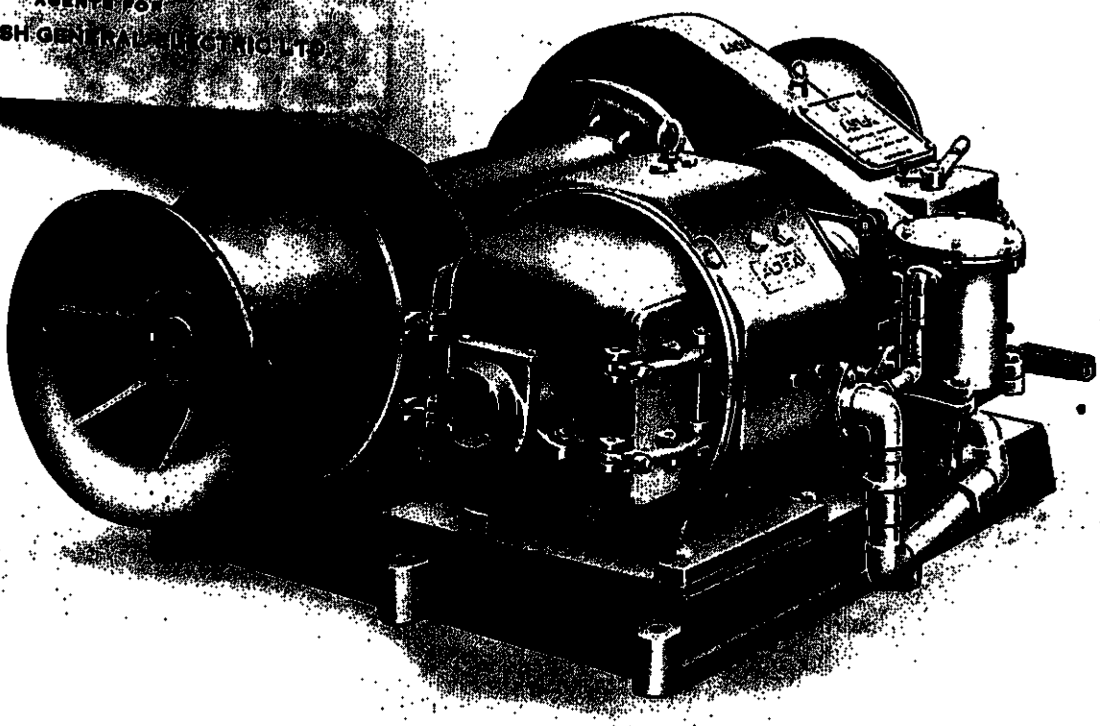
SWEDISH GENERAL ELECTRIC LTD
5 CHANCERY LANE—LONDON

MONTHLY REVIEW

VOL. IV 1927

All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesteras, Sweden.
Permission is given to reprint articles or extracts from this journal, on condition that the name — Asea-Journal — is clearly stated.

APRIL No. 4



3 ton electric ship winch, Asea 1924 type.

ELECTRIC SHIP WINCHES.

The introduction of internal combustion engines and particularly Diesel engines for purposes of ship propulsion has made the question of the electrification of auxiliary machinery an important one, since the use of a special steam plant on board for supplying such machinery is a half measure which is uneconomical and also unsuitable from several points of view.

The most desirable way of approaching the matter was obviously the development of a practical electric warping and cargo winch which should be capable of taking the place of the steam winch hitherto almost universally employed and which, although found exceedingly satisfactory from the point of view of reliability and simple operation, suffered from a number of disadvantages including poor efficiency and difficulty with long steam pipes *etc.* which in many respects made the motive power uneconomical and unsuitable.

The production of a reliable electric ship winch may seem at first sight a simple matter, but experiences in connection with the first large motor vessel equipped in this way demonstrated that the question was by no means an easy one, and this was also clearly shown by the fact that one of the best known electrical engineering firms in the world failed in an attempt in this direction. The greatest difficulties arose in the construction of electric motors and operating gear which would be fully reliable under the working conditions, and in this respect special attention had to be given to the difficult atmospheric conditions, and to the careless handling, overloads *etc.* to which this class of gear is always subjected. It must also be remembered that great weight is placed on easy operation and speed regulating possibilities, and in this regard the steam winches formerly used were exceedingly satisfactory.

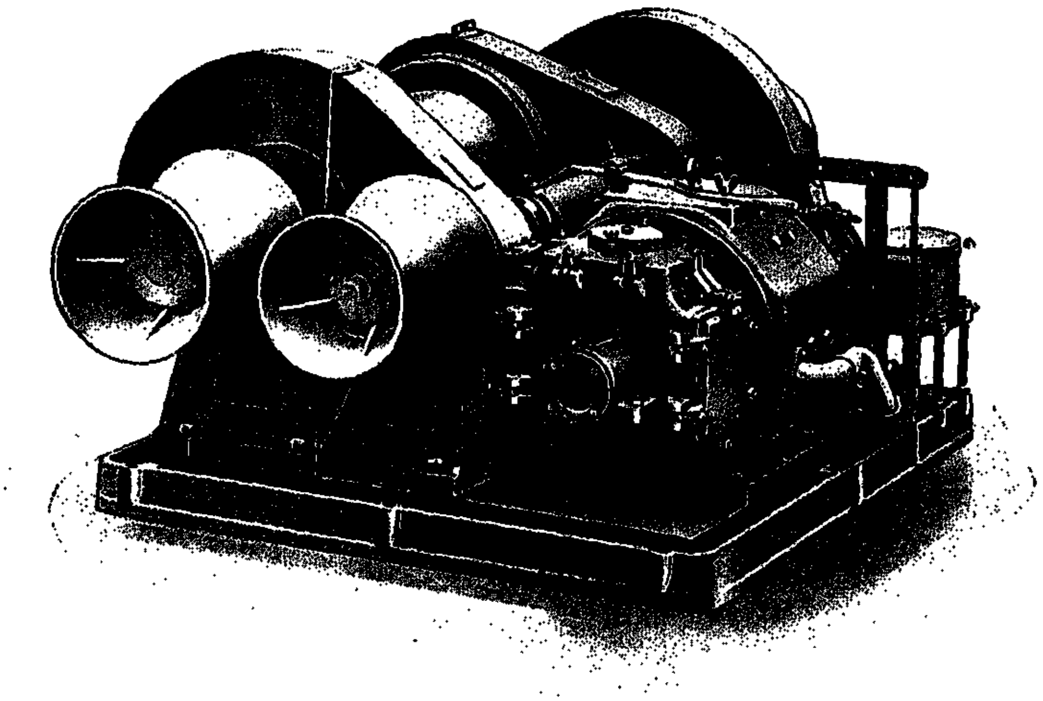


Fig. 1. 3 ton standard electric ship winch of Asea 1912 type.

The fact that the first electric ship winches manufactured by a number of different people were found to be very badly designed was due to underestimating the requirements and the character of the work which such machinery has to perform, manufacture being undertaken before sufficient experience had been obtained.

After the first attempts had ended in failure the specifications for electric ship winches were naturally made exceedingly exacting. Thus it was demanded that winches should be of particularly conservative design both as regards the electrical and mechanical parts and with regard to the electrical operation it was stipulated that they should be capable of being operated "by any person whatever in any port in the

world without any instructions being necessary, beyond the man in charge being told to turn the handwheel in one direction for raising a load, and in the other direction for lowering it". It must be remembered that the winches are in general not worked by the crew of the vessel but by odd labour, dock labourers *etc.* and on this account any instructions regarding the operation of the winch may be assumed to receive no attention at all.

The actual work as before mentioned may be forced to the highest degree and work may continue over the whole 24 hours without cessation, and the driving motors may be started from 4 to 5,000 times within this period.

When Asea accordingly in 1912 decided to go in for the production of electric ship winches the greatest possible attention was given from the beginning to the working and design of the various details, having regard to the experience which was then available. The first complete winch equipments were supplied in connection with two Diesel engined motor vessels which were being constructed by a foreign shipyard for Swedish owners, and in spite of the very difficult conditions which have been referred to they were found to be so satisfactory that for several years Asea was the only firm considered for the supply of such material, both by the owners of these vessels and the shipyard in question. The market for this class of gear has since increased continuously as the demand for such machinery has grown, although there was naturally a certain set-back due to the war.

During the past few years the demand for electric ship winches has again increased considerably and it appears certain that the output will be further increased as overseas commerce regains it normal conditions.

Up till last year Asea had delivered over 1,000 complete electric winch equipments to over 30 shipping companies for more than 100 vessels trading to most countries within and outside Europe.

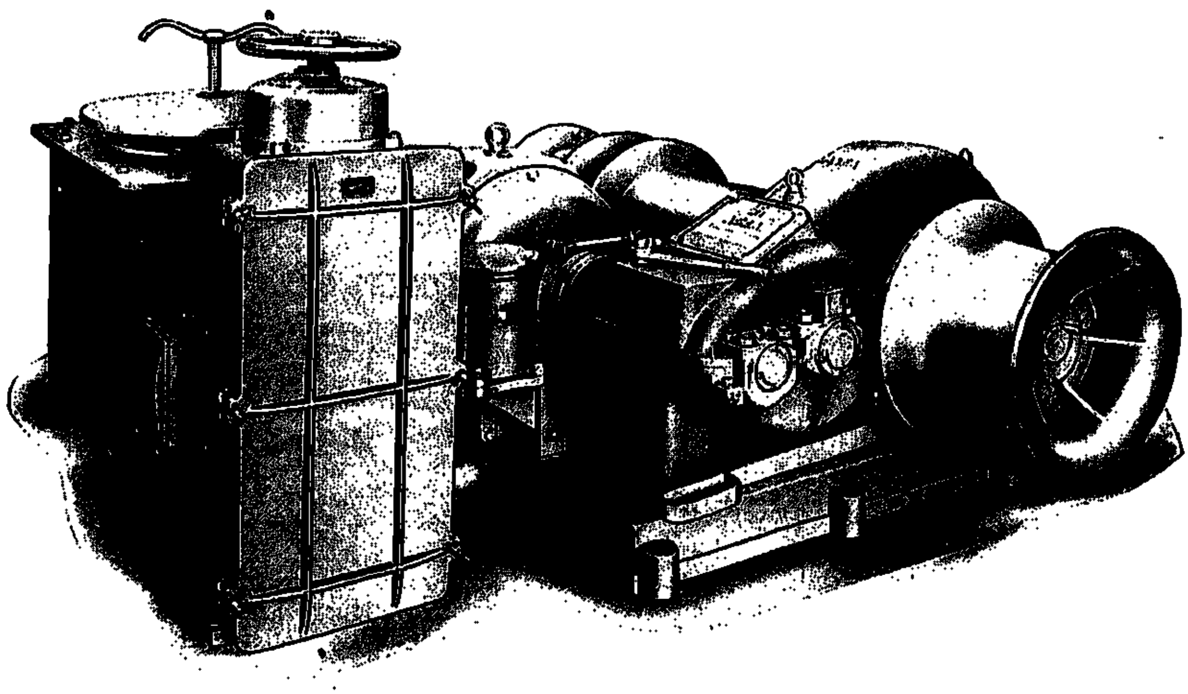


Fig. 2. 3 ton standard electric ship winch of Asea 1924 type.

The construction which was adopted for the first winches was maintained practically unchanged until 1924 and the equipment in question is illustrated in fig. 1.

The mechanical part, as will be gathered from the figures, consists of cylindrical gears, a rope drum and warping heads, the shafts being carried in ordinary cast iron brackets and the whole, including the motor and brake gear, mounted upon a common bedplate.

Two different speeds for greater and smaller loads can be obtained by a gear at the end of the winding drum which when required can be thrown in and out by means of a claw coupling on the intermediate shaft.

The winding drum gears are both of cast

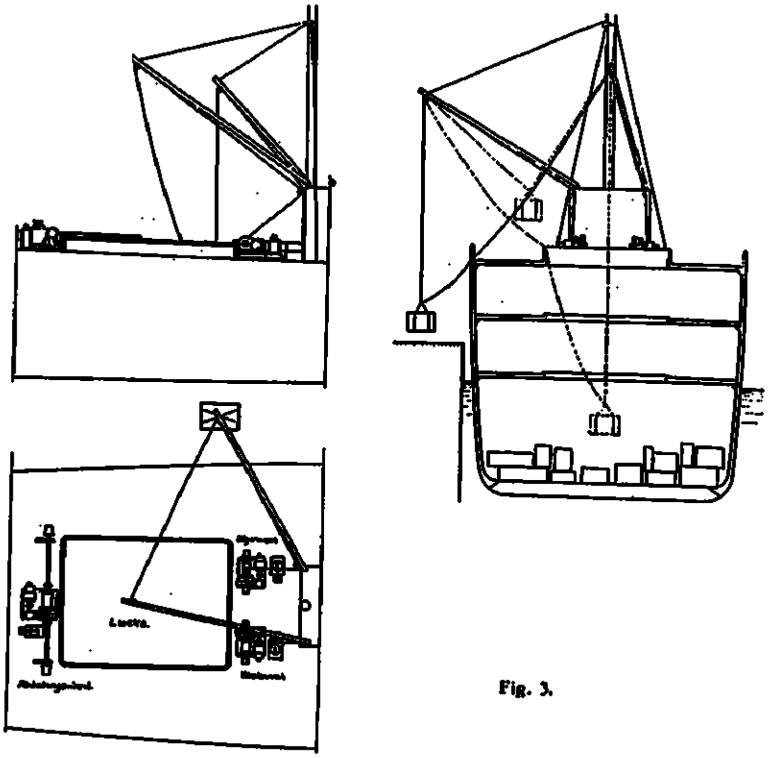


Fig. 3.

iron and have cast helical teeth. The motor gear, which is a large wheel of cast steel and a pinion of forged steel, has cut teeth. The first gear is covered by an ordinary sheet iron protection to prevent the rope, or anything of a like nature, finding its way into the gear. The motor gear is entirely enclosed in a sheet cover. The motor bearings and intermediate shaft bearings are provided with brass bushings. The drum shaft, however, runs direct in the cast iron.

The electrical equipment is of an entirely special type, both as regards motor, starting gear, and brake magnet and all these are of enclosed water tight pattern, so that they can, like the mechanical parts, be placed on the open deck without any risk of damage by the sea breaking over them. The motor is provided with covers which may be unscrewed at the commutator end for inspection.

Enclosed in the controller housing are effective and simple safety devices consisting of overload and no volt relays and also a manually operated circuit breaker, the handle being outside the controller. The starting and regulating resistances are placed in a welded sheet steel tank which is made fast by screws to the back of the controller. To provide ventilation there are two air valves which when opened provide complete protection against rain and splashing water, and when closed are entirely water tight. These air valves are closed on leaving port. When the winches are to be used again they are opened so that effective cooling of the resistances is obtained.

At a time somewhere about 1922 shipping companies began to demand greatly increased capacity and extra silent running electric winches and steps were immediately put in hand by Asea for the development of an entirely new type.

The new type of winch which was placed on the market in 1924 and has been supplied ever since has been found entirely satisfactory in all respects. The general appearance can be gathered from fig. 2 and from the illustration on the front page.

As in the case of the older type, the mechanical parts are exceedingly strongly designed, but the general arrangement has been considerably altered. There is only one gear on to the hoisting drum and the two speed device has been placed on the extended shaft of the motor.

All gears have steel wheels and pinions made from forged steel of special quality and all the gears have teeth carefully cut by a special process and run in an enclosed casing strongly built from cast iron and which carries the bearings for the various gear shafts.

All bearings are provided with brass bushings; the motor shaft bearings have oil rings and the remaining bearings are arranged with wick lubrication. The brake gear is of a simplified and improved design.

The electrical equipment is practically unaltered but a number of improvements have been introduced, among these being the provision of hinged covers in the end shield at the commutator end of the motor, heavier contact fingers on the controller, *etc.* In addition there is a main disconnecting switch in one division of the controller casing so that when carrying out inspection or repairs the whole controller and equipment can be made entirely dead.

The new type of winch can also be arranged with a separate foot brake which provides additional safety and is also required in order to meet the regulations in certain countries.

As explained above, the Asea winches have always been provided with spur gears and these, especially in the case of the newer type where extra careful workmanship has been used to

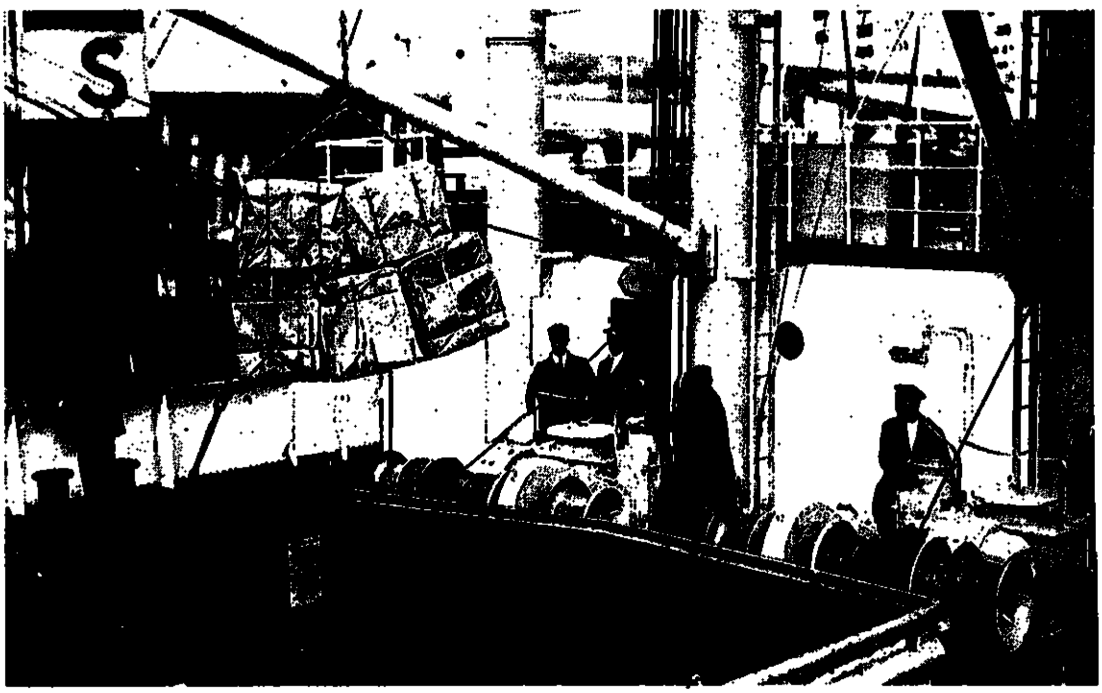


Fig. 4. Standard arrangement of ship winches "Asea" type on board M/S Agra.

obtain silent running, have the advantage of much higher efficiency than reduction gears employing a worm and worm wheel which are used by a number of our competitors.

The winches of the type described above are intended for raising and lowering cargo, but in certain cases they can also be arranged for warping work *etc.* and are then provided with one

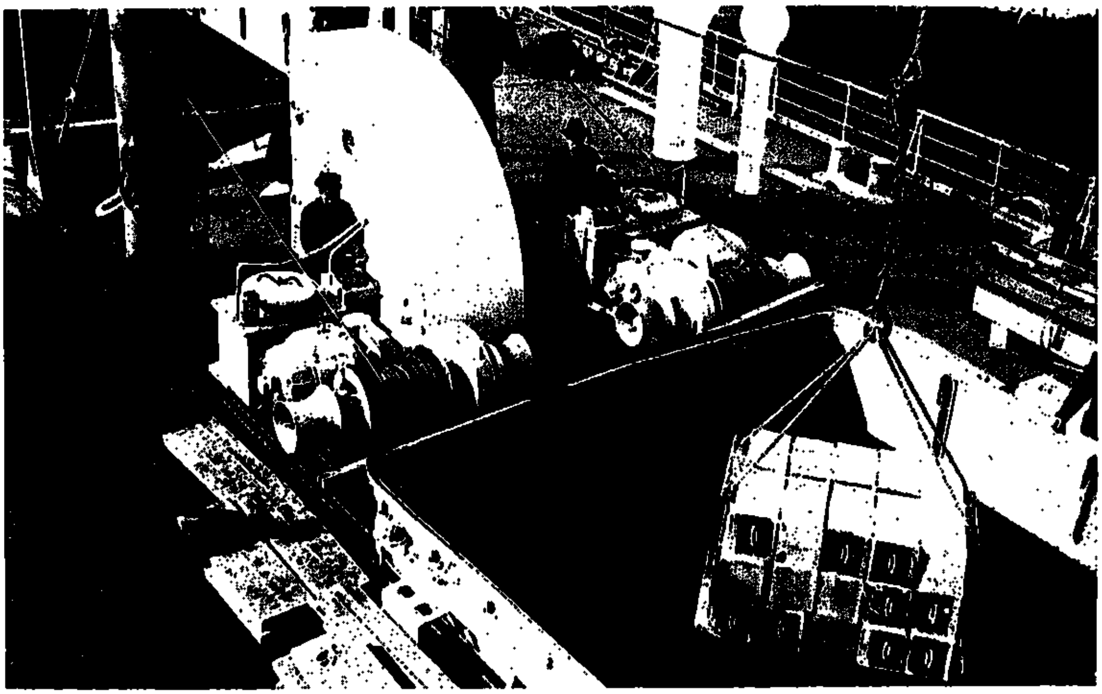
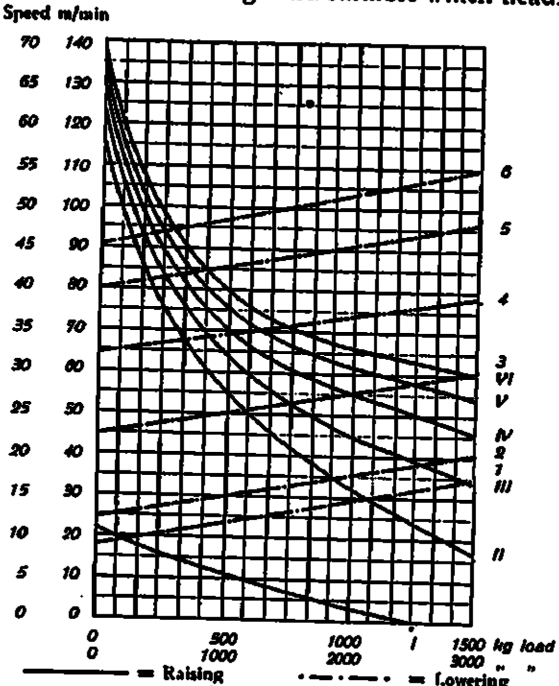


Fig. 5. Standard arrangement of ship winches "Asea" type on board M/S Annie Johnson.

or two shaft extensions placed at the ends of the winding drum. These shaft extensions are fitted with outboard bearings and suitable winch heads.



Motor: 25 h.p.
Fig. 6.

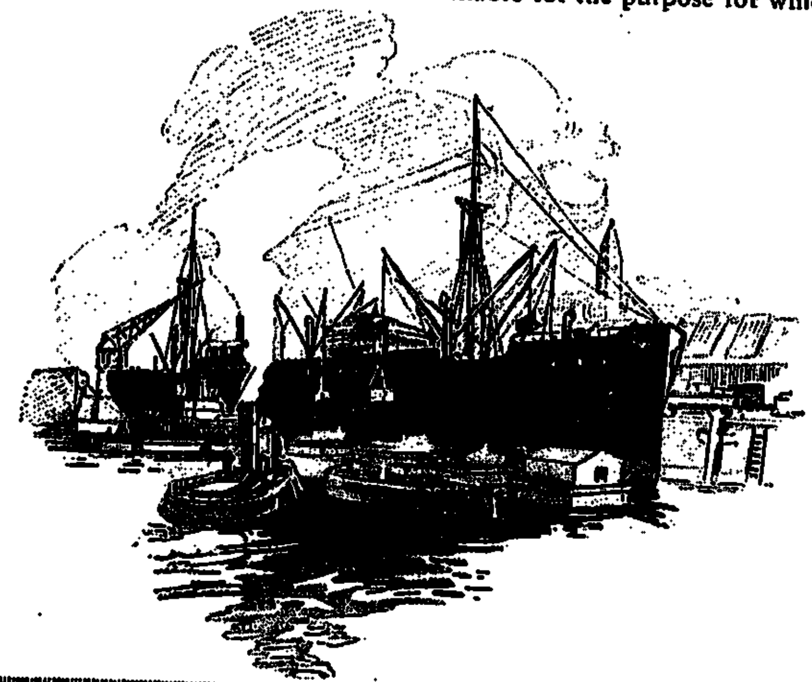
When the winches are arranged for loading and unloading they are generally placed in pairs by the hatches and it is usual for them to work in conjunction with one another and with two derricks as shown in fig. 3. In certain cases one winch can be used for each derrick which is then arranged so that it can be swung round. The layout of a warping winch is also shown in the same figure.

The electrical equipment of these winches is arranged exclusively for D.C. supply and in general for 220 volts. In a few cases winches for 110 volts have been supplied.

The various lifting and hauling powers for different winch sizes are given in the table below, together with the raising and lowering speeds at various loads and with the controller in various positions, and these are shown diagrametically in fig. 6.

Size Tons	Lifting or hauling power, kg	Lifting speed m/mins. full load approx.	Lowering speed m/mins. full load approx.	Motor h.p.
1.5	1500	56	110	25
	1500	40	82	17
3	3000/1500	28/56	55/110	25
	»	20/40	41/82	17
5	5000/1500	25/80	52/173	35
	»	17/56	33/110	25
	»	12/40	25/82	17

We may add in conclusion that as far as this class of machinery is concerned Asea has well maintained the position which is so necessary for a firm when competing in the world market, the principle being always kept in view that every machine manufactured must be entirely suitable for the purpose for which it is intended.



A UNIT FOR ASYNCHRONOUS PARALLEL WORKING BETWEEN TWO UNDERTAKINGS WITH LOAD AND POWER FACTOR REGULATION.

At the end of 1923 Asea delivered to Karlstad Electricity Works, Sweden, a converter set of a rather special nature. The Customers have expressed great satisfaction with this plant and have been kind enough to supply us with a number of particulars and results of working, so that it appears to us that a full description of the set may be of great interest to readers of this Journal.

The object of the set is to generate D.C. for the town load and also to allow transference of power between two A.C. networks which while running normally at a frequency of 50 cycles do not work in parallel, the frequency of each being maintained within a tolerance of ± 3 %. The set was designed to meet the following requirements:

The Karlstad Electricity Works have a contract with the Dejefors Kraft & Fabriks A.-B. to supply them with 1,200 h.p. three-phase A.C. This power the purchasers wish to utilise completely, disposing of it partly by direct distribution as A.C. and partly by the generation of about 350 kW D.C. at 500 volts. When these demands have been met, any surplus power is transmitted to a distribution network known as the Kohlsater system which is supplied by the Company's own power station at Kohlsater and which is run in parallel with the Trollhattan Power Station. In case the amount of power obtained from Dejefors is insufficient power is taken from the Kohlsater system, in the first place for generating D.C. and secondly in exceptional cases for generating A.C. for supply to the 3,000 volt network, connected to the line from Dejefors. These requirements have to be fulfilled with either system working at any frequency between 48.5 and 51.5, the frequency fluctuations in the two systems being quite independent of one another. It was desirable in addition that the three-phase machines embodied in the converter set should work with a power factor of unity or 0.9 in order to improve power factor conditions on the respective systems.

To meet the above conditions a number of different methods were investigated. First of all the use of two separate motor generator sets was examined, these consisting of synchronous motors and D.C. generators working in parallel on the D.C. side and with load regulation carried out in the ordinary way. This proposal was found to be expensive and above all the efficiency of the transference of power between two three-phase systems was rather low, since in this case the load must pass through four machines. Another proposal was to use a slipring induction motor wound for 3,000/3,000 volts, 50 cycles, the stator being supplied from the Dejefors system and the rotor from the Kohlsater system. The two networks would in such a case be linked up through the common field excited in the machine. The rotor would rotate slowly in one direction or the other at a speed determined by the difference in periodicity between the two systems. If the shaft were not subjected to any torque there would be no transference of power between the stator and rotor. The necessary torque for power regulation could be supplied to the shaft through a gear with a suitable ratio. The secondary side of the gear would be connected to an induction motor having a hysteresis starter connected in the rotor circuit and designed for maintaining constant torque independently of the speed. The hysteresis starter could be devided into several small parallel connected units and the power regulated by connection or disconnection of these sections of the starter. A unit of this kind would require magnetising current of an appreciable amount which would have to be taken from the two systems. As it would be necessary to provide a separate unit, both for power factor correction and for generating D.C., the arrangement would become more complicated than appears at first sight and the cost is found to be higher than that of the arrangement finally adopted. A third method deserves brief reference as it would have fulfilled the requirements, but in this case it was found to be more expensive than the system finally adopted. This proposal embodies two units, a main unit and a regulating unit. The main unit would consist of a synchronous motor running on the Kohlsater system and an induction motor running on the Dejefors system. The synchronous motor would determine the speed of the set and the induction motor would accordingly run either with slip, synchronously or oversynchronously in accordance with the conditions obtaining at any particular time. To obtain the necessary regulating voltage to be applied to the sliprings of the induction motor a regulating unit would be used consisting of a three-phase commutator machine driven by a three-phase induction motor. The commutator machine would be built on the Scherbius system with compensating winding and commutating poles, so designed that with 48.5 cycles on the Dejefors system and 51.5 cycles on the Kohlsater system it could generate

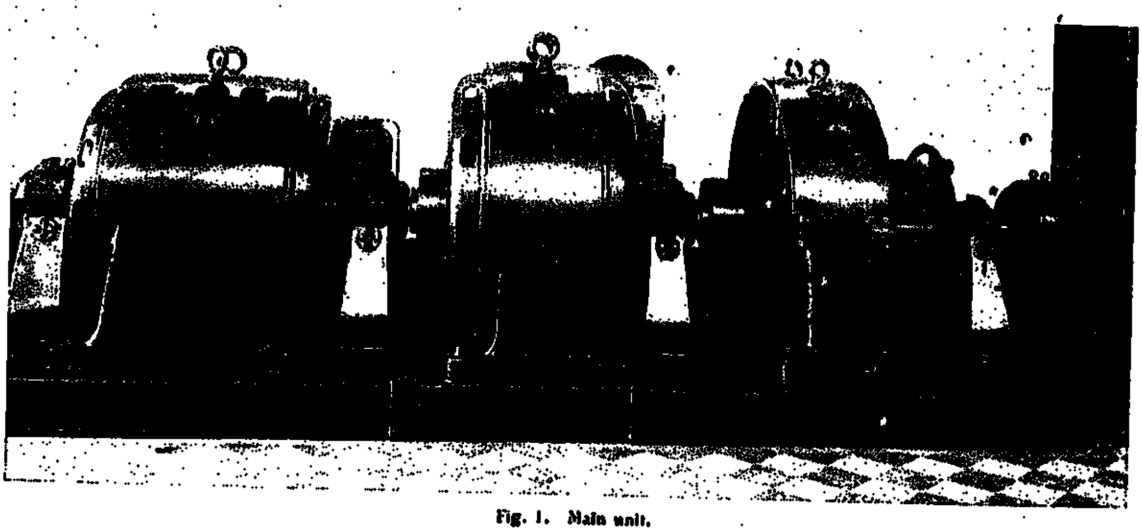


Fig. 1. Main unit.

the power which would have to be supplied to the sliprings of the induction motor to make it run oversynchronously at full output and a speed corresponding to 51.5 cycles. To make it possible to generate the power for regulation at the periodicity existing at the sliprings of the induction motor, the commutator machine would be magnetised from a frequency converter mounted on the shaft of the main unit and built as a Schrage machine with D.C. and A.C. windings in the same slots. The frequency converter would be fed through three sliprings from the same supply as the induction motor. The armature is surrounded by the stator without slots or winding. Since the converter is so connected that the rotor field moves in the opposite direction to the direction of rotation of the set, it follows that the field rotates at the slip frequency with relation to the stator. A voltage is thus obtained at the commutator which has the same periodicity as the rotor current in the induction motor. Load and power factor are regulated by altering the magnitude and direction of the magnetising voltage for the Scherbius generator and this is done by rotating the movable brush gear of the frequency converter.

The arrangement which, after very long investigation, was finally adopted as best fulfilling all the requirements outlined is more fully described below and consists of two units, a main unit and a regulating unit. Before treating the general working of the arrangement we must give a short description of the various machines included in the set.

I. *Main unit.*

This embodies four machines Nos. 1—4 arranged on a common bedplate.

No. 1. A three-phase synchronous machine, type G 27, 8-pole for 750 r.p.m. at 50 cycles, 3,000 volts giving 500 h.p. as a motor with cos $\varphi = 0.9$, and as a generator taking 590 h.p. and giving out 500 kVA at cos $\varphi = 0.8$.

No. 2. A three-phase asynchronous machine, type TM 104, 6-pole for 3,000 volts, 50 cycles and designed at 750 r.p.m. for an output of 500 h.p. mechanically at the shaft, and 166 h.p. electrically at 330 volts and 12.5 cycles at the sliprings, corresponding to 25 % slip. In certain cases this machine can also run as a generator being then excited through the sliprings with suitable slip energy for this purpose.

No. 3. A compound wound D.C. generator type K 19, 350 kW, 500—460 volts, 750 r.p.m., furnished with a weak series winding which acts in opposition when running as a generator.

No. 4. A shunt wound exciter for the synchronous machine of the regulating unit, type TD 71, 20 amps, 70 volts, 750 r.p.m. This machine, although really belonging to the regulating unit, has been placed on this set because the speed of the regulating unit is subjected to considerable variation when the periodicity of the two supply systems changes.

Accessories to the main unit include field rheostats for the G 27, K 19 and TD 71 machines, and starters for both TM 104 and K 19 machines, designed for starting and parallelling. On the shaft of the set is mounted an overspeed centrifugal switch in the release circuit of the oil switches for the G 27 and TM 104.

II. *The regulating unit.*

This embodies two machines, Nos. 5 and 6, on combined bedplate.

No. 5. A synchronous machine, type G 23, constructed 2-pole and as a motor designed for 143 kVA, 330 volts with cos $\varphi = 0.9$ and 750 r.p.m.

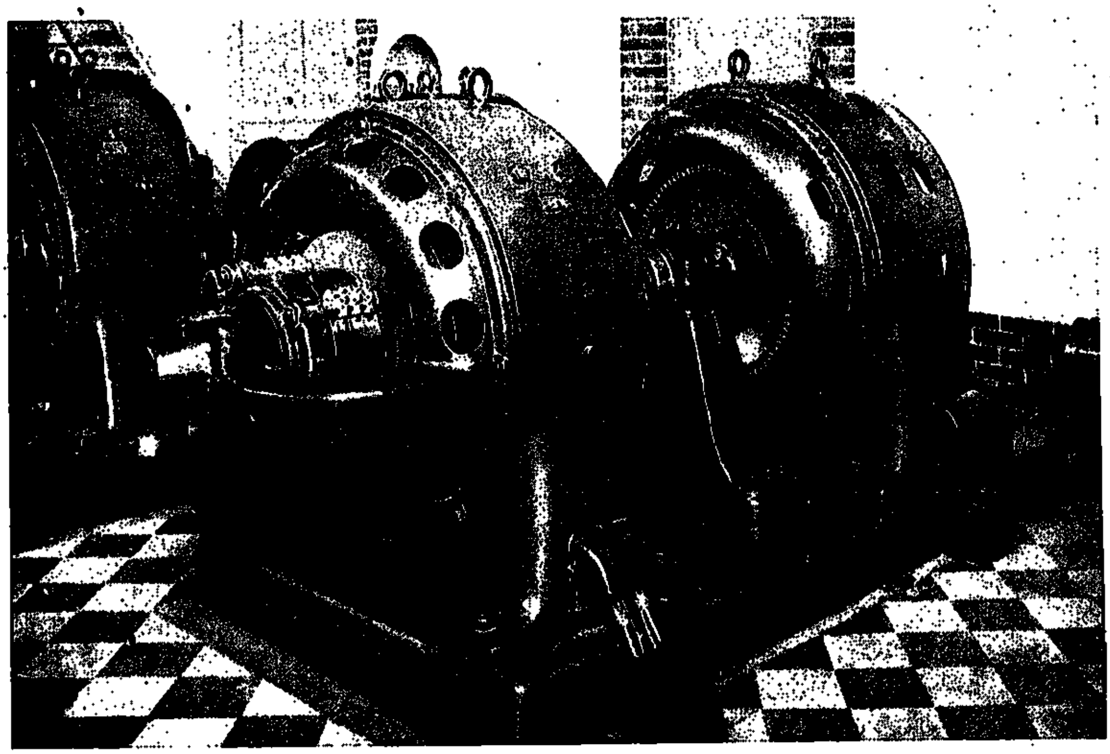


Fig. 2. Regulating unit.

This corresponds to 12.5 cycles, but the machine is capable of working between 9.9 and 15.5 cycles with a constant current of 250 amps. and with a voltage directly proportional to the frequency, thus varying between 260 and 410. The rotor of this machine is of special construction, the field consisting of a single magnet core between the two pole shoes. The shaft is not carried through the rotor but is divided and has flanges which are bolted up on each side.

No. 6. A compound wound D.C. generator, type K 16, 80—130 kW at 590—910 r.p.m., 500 volts, having series turns which act in opposition when the machine runs as a generator.

The regulating unit is provided with a starter for the D.C. machine, the set being started from the D.C. side, and a field rheostat for regulating the voltage of the D.C. machine. In normal service this rheostat is not used and is substituted by a Thury regulator acting in the manner described later. As in the case of the main unit this set is fitted with a centrifugal overspeed switch acting in the release circuit of the oil switches supplying the G 27 and TM 104 machines.

The whole plant is connected up as shown in the diagram, fig. 3. Thus the synchronous machine G 27 is connected to the Kohlsater system and the asynchronous machine TM 104 to the Dejefors system. The periodicities on these two systems vary by ± 3 % and the maximum difference is accordingly 6 %. The speed of the main unit is fixed by the synchronous machine and is accordingly 750 ± 3 % r.p.m. The periodicity at the sliprings of the asynchronous machine is fixed by a number of poles on this machine and the relative speed between the stator field and the rotor.

Frequency at sliprings

$$\nu_r = (n_a - n_s)\frac{p_a}{120};$$

$$= \nu_a - \frac{p_a}{p_s}\nu_s;$$

$$= \nu_a - {}^8/_1\,\nu_s;$$

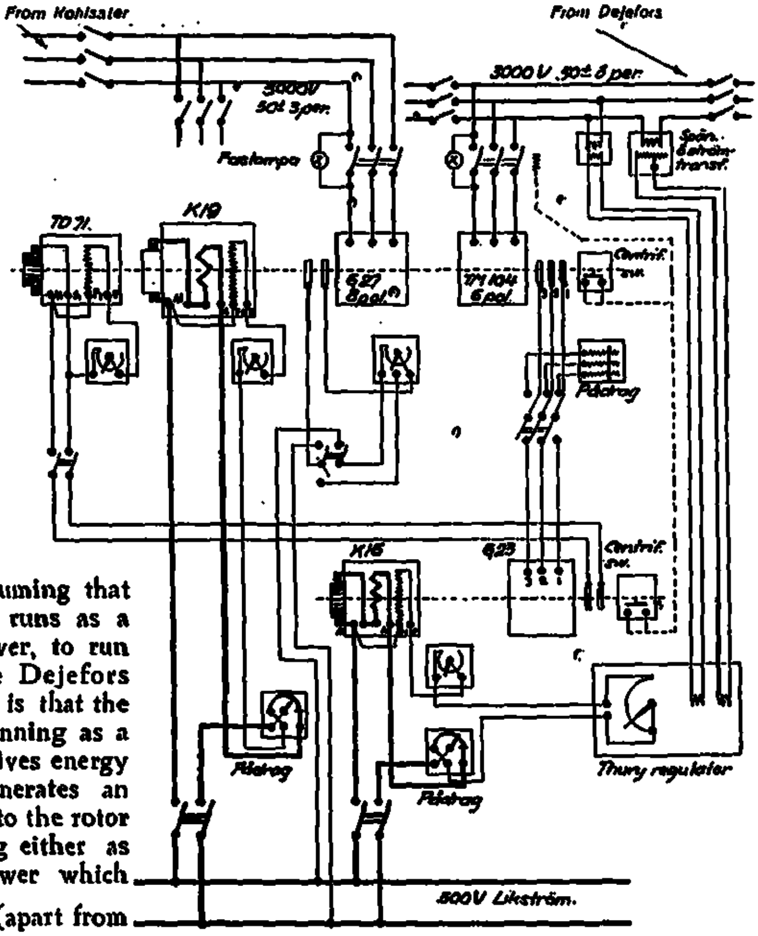
where p_a, p_s, n_a, n_s, ν_a and ν_s are the number of poles, synchronous speed and frequency for the asynchronous and synchronous machines respectively.

With $\nu_a = 50 - 3\,\%$ periods and
$\nu_s = 50 + 3\,\%$ „ ν_r is a min. = 9.9 per.
With $\nu_a = 50 + 3\,\%$ „ and
$\nu_s = 50 - 3\,\%$ „ ν_r is a max. = 15.5 per.

Although the differences in the periodicity of the two supplies are thus relatively small, the regulating unit is subjected to frequency changes and accordingly speed variations of approximately + 25 % and − 20 % reckoned on the normal value.

As the same current traverses the rotor of

the asynchronous motor and the stator of the synchronous motor in the regulating unit, it is clear that when we regulate the load on the last named machine the torque of the asynchronous motor is also regulated, and in addition if we allow the synchronous motor to run with cos $\varphi = 0.9$ leading, the power factor of the asynchronous motor is maintained = 1. The output of the synchronous motor is transmitted to the D.C. generator K 16 on the same shaft which works in parallel with the D.C. generator K 19 in the main unit, and thus the output of the regulating unit and also of the asynchronous motor can be regulated by suitably adjusting the field excitation of the generator K 16. This is assuming that the asynchronous machine TM 104 runs as a motor. Should it be required, however, to run from the Kohlsater system to the Dejefors system the only difference involved is that the K 16 runs as a motor, the G 23 running as a generator. As the TM 104 then receives energy through the rotor sliprings, it generates an output P_a in the stator proportional to the rotor power supplied, since when running either as a motor or as a generator the power which passes through the sliprings $= \frac{\nu_r}{\nu_a} \cdot P_a$ (apart from the losses in the machine). The TM 104 thus regulates its performance entirely on the impulses received from the synchronous machine G 23. The synchronous machine connected to Kohlsater runs as a motor or as a generator according as the power taken by the TM 104 is less or more than the power which the two D. C. machines generate for the D.C. load.



Faslampa = Synchronising lamp. Spän. o. strömtransf. = Potential and current transformers. Pådrag = Starter. 500 V Likström = 500 V D.C.

Fig. 3.

Since as before mentioned the speed of the regulating unit varies a good deal under different frequency conditions in the two systems and as the load on the generator K 16 must be made to vary so that constant torque is maintained irrespective of the speed it will be appreciated that it would be very difficult to regulate the field rheostat of the K 16 by hand. To overcome this trouble the rheostat in question has been replaced by a Thury regulator, worked by current and potential transformers in the incoming line from Dejefors. The regulator is so calibrated that it maintains constant the 1,200 h.p. which has been contracted for. As only 666 h.p. can be dealt with by the asynchronous motor in the converter set the rest must be absorbed by direct distribution and it is necessary for the attendants in charge of the plant to take care that the converter set is not subjected to too great a load in the event of a decrease taking place in the demand for direct A.C. energy. This may happen due to the efforts of the regulator to keep the amount of power coming in from Dejefors constant. The current transformer in the Dejefors line which supplies the regulator is furnished with tappings, so arranged that the incoming power can be adjusted between 1,000 and 750 kW in ten steps.

It will be clear that with a set of this kind, where several machines are coupled mechanically and electrically, it is impossible to prevent some hunting when load and frequency variations take placed. In constructing the machines a number of arrangements have been embodied with the idea of limiting the mechanical and electrical stress which can occur. The D.C. machines are furnished with a weak opposing series winding, and in this way a very flexible coupling on to the D.C. system is obtained. In the regulating unit the three-phase motor

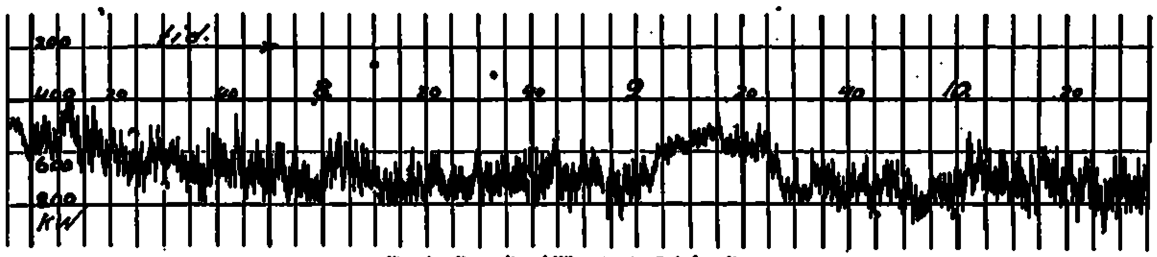


Fig. 4. Recording kW-meter in Dejefors line.

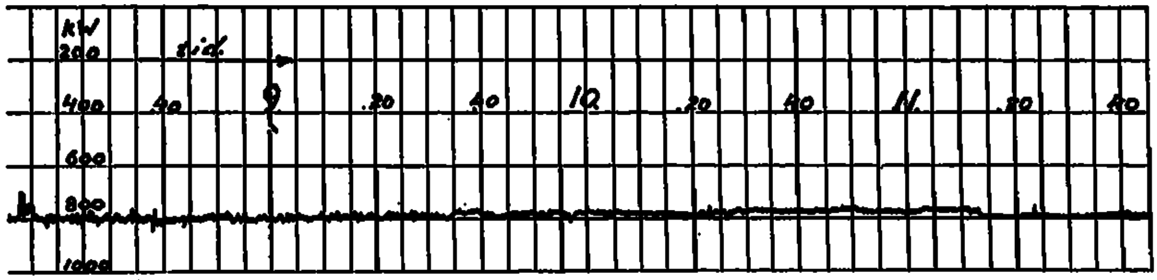


Fig. 5. Recording kW-meter in Dejefors line.

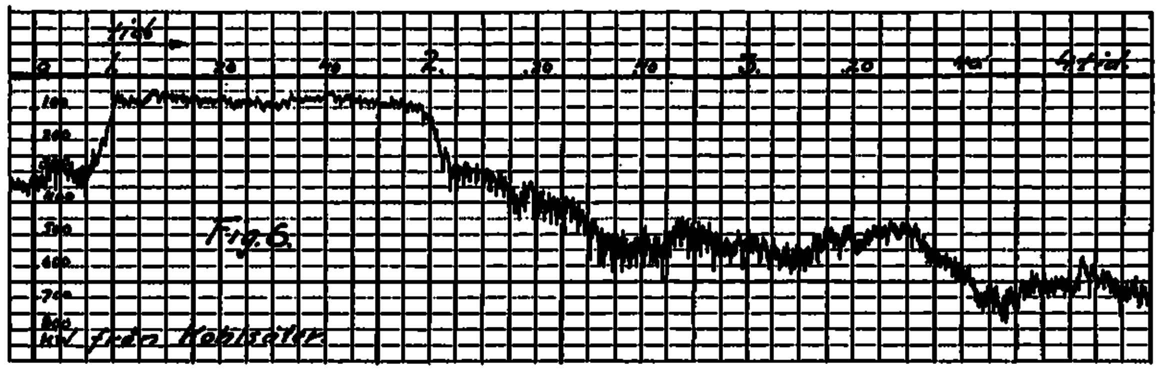


Fig. 6. Recording kW-meter in Kohlsater line.

has been made synchronous to allow of satisfactory power factor correction, although an induction motor would have had valuable qualities as regards adjustability with rapid variations in load and frequency. In this case, however, the synchronous motor is a two-pole machine and this design allows of quite a considerable amount of momentary slip, without losing the advantages of overload capacity required in operation. To avoid giving rise to hunting by regulating the unit too rapidly a relatively slow acting automatic regulator has been chosen. It can be seen from charts taken from the recording wattmeters that the regulator works with great precision and any necessity for a quicker acting regulator has not arisen.

It has been found that fears with regard to causes of hunting were well founded and the conditions under which the set has to operate have upon occasion been exceedingly difficult, momentary variations in frequency having arisen which are much greater than those for which the set was designed. The set when run in the test room was naturally subjected to a D.C. load which was applied and removed gradually, but under actual working conditions very heavy shocks have been imposed on the D.C. side. As a stronger series winding is furnished on the K 16 D.C. generator the set has, however, always worked entirely satisfactorily as will be seen from the report furnished by the customers.

A particular advantage of the arrangement which has been employed is the simplicity with which regulation can be made automatic, the regulating all being done by a single field rheostat. Another advantage of the system chosen is that the regulating unit is not, so to speak, unproductive but generates D.C. energy at the same time as it performs its regulating functions, and in this respect the use made of the machines is as high as in motor generators in general. Power factor adjustment can be carried out on both systems through the synchronous machines.

Starting up and loading the set is done in the following way:

If the amount of D.C. power available is not too low, both units can be started from the D.C. side and the respective machines in the main unit parallelled.

In general, however, the procedure is to start up the main unit by means of the asynchronous motor, making use of a rotor resistance giving 25 % slip to enable the synchronous motor to be parallelled. The asynchronous motor is then disconnected and the rotor circuit switched over from the starting resistance to the regulating unit. The regulating unit is then started from the D.C. side, after which the two D.C. machines are connected to the busbars. The asynchronous motor is excited from the G 23 and parallelled, after which the load is taken up by disconnecting the starter and adjusting the field rheostat. Afterwards, the automatic regulator is connected in the field of the K 16. By suitably exciting the G 23 the desired power factor for the asynchronous motor is obtained.

As mentioned above, a very comprehensive report has been received from the Customers regarding the working of the set and we may perhaps be forgiven for quoting the following extracts:

"The set has now been in continuous service day and night for a whole year and has always worked exceedingly well, no interruption having occurred in any way traceable to its working."

"The set has withstood very well exacting conditions imposed by very rapid alterations in frequency, *e.g.* when one of the Dejefors power stations has been suddenly shut down causing a sudden decrease in frequency on this system, from 50 to 47 cycles."

We include further some reproductions of charts taken from registering kW-meters in the Dejefors and Kohlsater lines. Fig. 4 is a chart from the kW-meter in the Dejefors transmission line taken before the installation of the set, the load regulation being adjusted by hand directly from the turbine governors. Fig. 5 shows a similar chart after the installation of the set, the regulator maintaining as shown a constant load of 1,200 h.p. Fig. 6 is a chart from a kW-meter in the Kohlsater line from which the variable part of the power requirement is taken.

Duplicate busbars are provided for both lines so that the asynchronous motor TM 104 and the synchronous motor G 27 can be interchanged. When the D.C. demand is high the TM 104 is run on the most loaded line so that the K 16 generator is in a position to deliver its largest output.

While the set described above has to act on the one hand as a converter for the production of D.C. from a three-phase supply available from two separate sources it has, on the other hand, the no less important function to perform of transferring power between the two three-phase systems and in this last respect it has to make possible the full utilisation of the power purchased from one of them (Dejefors) and also in the event of a breakdown on this system it has to provide for a supply from the other.

It would naturally be possible to secure full utilisation of the power purchased with a more simple arrangement, *e.g.* with two synchronous machines direct coupled to a D.C. generator or — if the D.C. convertion were carried out separately — by parallelling the two systems directly, *provided* the purchaser was in a position to control the governors of the turbines and the regulators in the power suppliers station himself, a condition which, however, is not possible on account of divided interests and would in addition be particularly difficult from a practical point of view. In this case also, the two systems to be worked together are of large capacity in relation to the power to be transferred between them, and each separate system is subject to frequency alterations of its own, brought about by load conditions and accordingly it is clear that the connecting links would be subjected to serious and dangerous stresses if parallel working were made directly synchronous.

The special characteristic of the arrangement we have described is that parallel running is flexible and capable of automatic regulation while, at the same time, the power factor on both sides is well attended to.

THE THEVENIN—PLEIJEL'S THEOREM AND SOME APPLICATIONS.

The calculation of phenomena which involve disturbance of symmetry in a three-phase network often presents great difficulties, in that it is necessary either to make use of the complicated methods of calculation which employ unsymmetrical three-phase vectors, or else to apply Kirchhoff's laws to the complete three-phase network with separate E.M.F's in each phase, whereas in the case of symmetrical phenomena a three-phase circuit can be treated generally on the same lines as a single-phase circuit.

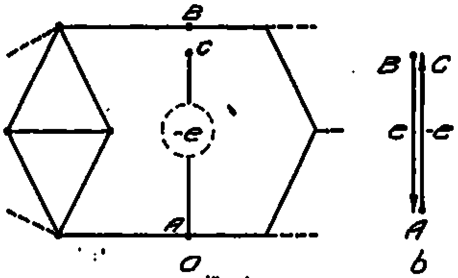


Fig. 1.

Even calculations of symmetrical phenomena can, however, be awkward and unwieldy in the case of complicated circuits, especially networks with several generating stations operating in parallel.

Calculations can often be greatly simplified by the use of a theorem which was enunciated in 1883 (for D.C.) by the French scientist Thevenin. The theorem, however, appears to have been generally forgotten until revived by Pleijel, who showed that it could also be applied to A.C. and to transient phenomena.

As the theorem appears, even now, to be very little known, it may not be out of place to draw attention to its wide application. The theorem is as follows:

The changes of currents and voltages, which take place in a network when two points in it are connected to one another (whether directly or through a given impedance), are identical with those which would be produced by an E.M.F. introduced in the connection between the two points, such that it is at each instant equal to that voltage which would have existed between the points if the connection had not been made.

In the case of steady A.C., the expression "at each instant" implies equality in magnitude and phase, but if the condition of the network is not steady, the voltage must first be calculated as a function of time (without the connecting lead) before the theorem can be applied.

The proof of the theorem is exceedingly simple. Assume for example that, in fig. 1 a, the points A and B are to be connected by the conductor A—C. If, before the connection is made, an E.M.F., $-e$, is introduced in the conductor A—C, equal in magnitude but opposite in direction to the voltage e between A and B, then the points B and C are, as shown by the vector-diagram, fig. 1 b, at the same potential and may accordingly be connected together without causing any changes in the remainder of the network. The E.M.F. $-e$ thus neutralises any change caused by making the connection, clearly indicating that any change is equal to the effect of a voltage $+e$.

An essential condition for the validity of the theorem is that inductances and resistances, *etc.* be independent of current and voltage, as otherwise superposition of the effect of different E.M.F's would not be admissible. Even in such a case, however, the theorem can be applied with reasonable accuracy, for example by assuming, for the iron in the circuit, a permeability corresponding to the final condition, provided that saturation effect is not of vital importance for the problem under consideration.

It is readily seen that the theorem is particularly applicable to the calculation of short-circuit phenomena and earth-fault problems, the problem in these cases being essentially that of the connection of two points previously insulated from each other. This applies especially in the case of earth faults, the majority of devices for signalling or automatic release in the event of an earth being so arranged that, under normal conditions, they carry no current or voltage. The changes in current and voltage (due to the earth) as calculated by means of the theorem are accordingly identical with the currents and voltages which arise in such devices on the occurrence of a fault. In addition, saturation effects are in general of minor importance

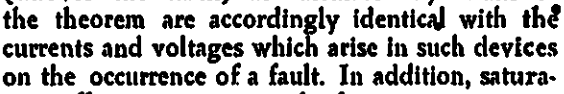


Fig. 2.

for cases of this kind, so that it is not usually necessary to consider the above-mentioned limitation of the validity of the theorem.

The use of the theorem is, however, not restricted to the calculation of disturbances in the system. For instance, the current distribution in a network can very often be very simply calculated by first assuming one conductor removed and then calculating, by means of the

theorem, the changes which would occur, if the conductor is reconnected. The examples given below are intended to illustrate the application of the theorem to problems of different kinds.

a) When calculating the short-circuit current

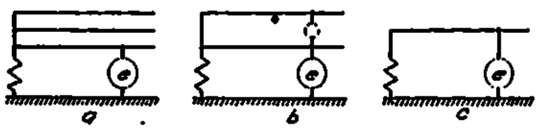


Fig. 3.

in a network with several generating stations operating in parallel, the combined effect of the machines may be replaced by an E.M.F. operating at the point of short-circuit and the generators then represented by their short-circuit impedances.

The case shown in fig. 2 a, with three generators working on one set of "busbars", is changed by this means to the equivalent diagram shown in fig. 2 b, which can be very simply calculated by ordinary series and parallel connection of impedances.

b) The calculation of earth currents is reduced, independent of the number of generating stations, to the calculation of the currents due to an E.M.F. between the earthed phase and earth, equal in magnitude to the voltage to neutral.

In this way we obtain, for a single outgoing line with earthed neutral at one end, the equivalent diagram shown in fig. 3 a. In practice, however, even this can, in most cases, be simplified in the following manner.

It is evident that the supposed E.M.F., e, does not cause any difference in potential between the two phases which are not faulty and these can accordingly be combined in one, as shown in fig. 3 b. In most cases earth currents are so small that the voltage drop which they cause in the lines can be neglected. The voltage between the two phases in fig. 3 b is thus so low that, while connecting them together certainly causes alteration in the currents of the individual phases, yet no noteworthy alteration is caused to the currents to earth, *i.e.* the unbalanced current in the lines. By "unbalanced" current is here understood the vector sum of the currents in the three phases.

The altered current distribution is, in general, of no importance, since earth leakage protection is usually based on the measurement of the unbalanced currents and of the pressure between the neutral point and earth. Further, since both these are normally zero, the equivalent diagram for calculation of the changes in state gives direct the currents and voltages which it is required to find.

The equivalent diagram for the above thus appears as shown in fig. 3 c. It will be seen that it closely resembles the diagram in fig. 2 b for calculation of short-circuits but is simpler in so far that, in the case of earth faults, attention need only be paid to those generating stations which have earthed neutrals. Furthermore one can usually completely ignore the voltage drop in the lines, which means that in the event of several earthed neutrals the individual current corresponding to each earthing point can be separately calculated and the results superimposed. On the other hand with calculations regarding earth faults the capacity of the line must be taken into account, which obviously complicates the problem.

In special cases, such as a network with Petersen coils, it may be desired to investigate the effect of line and transformer reactances and it is then of course necessary to work from the diagram in fig. 3 a, but even this gives appreciably simpler calculations than the ordinary direct method. It is, however, outside the range of this article to go further into the theory of such problems.

c) It follows from the Thevenin-Pleijel theorem that the current through a given conductor in a network can always be expressed by

$$i = \frac{e_0}{Z + Z_k}$$

where e_0 is the voltage which would exist between the points which are connected by the conductor if the conductor were removed, Z is the impedance of the conductor and Z_k a constant dependent on the remainder of the network, which constant can be calculated if it is possible to calculate the value of i for the case where $Z = 0$. If the current is in this case i_k, then

$$Z_k = \frac{e_0}{i_k}.$$

This is easily proved as follows:

It is clear that, in accordance with Thevenin's theorem, the current in the conductor is equal to that current which would arise if e_0 were connected in the conductor in question. The current caused by e_0 in the remainder of the network and, consequently, the

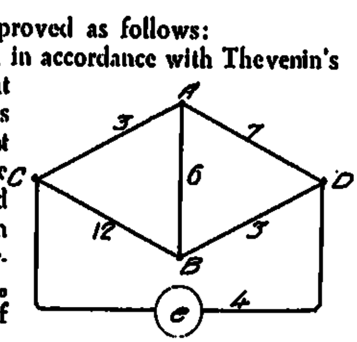


Fig. 4.

sum also of the currents flowing to the ends of the conductor, which is equal to the current

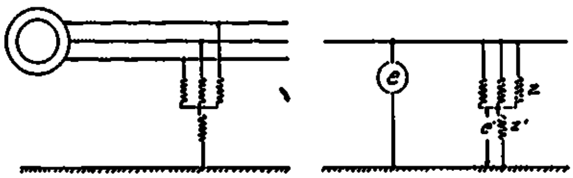
in the conductor, are obviously proportional to the voltage between its two ends, $e = e_0 - iZ$.

It is therefore possible to write

$$i = \frac{e_0 - iZ}{Z_k}$$

where Z_k is a constant, from which

$$i = \frac{e_0}{Z + Z_k}$$



a Fig. 5. b

In many cases e_0 and i_k can be calculated by simple methods and the solution of the problem easily follows. As an example a net resembling a Wheatstone bridge may be chosen as this is a type which often occurs. With resistance values as given in fig. 4 the following method is followed in calculating, for instance, the current in A—B:

1) With the conductor A—B removed the following are obtained:

Resistance of C—D: $\frac{10 \cdot 15}{25} = 6$

Voltage C—D: $\frac{6}{10} e = 0.6\, e$

Voltage C—A: $\frac{3}{10} \cdot 0.6\, e = 0.18\, e$

Voltage C—B: $\frac{12}{15} \cdot 0.6\, e = 0.48\, e$

$$e_0 = 0.48\, e - 0.18\, e = 0.30\, e$$

2) With A and B directly connected the following are obtained:

Resistance of C—D: $\frac{7 \cdot 3}{10} + \frac{12 \cdot 3}{15} = 2.1 + 2.4 = 4.5$

Current in C—D: $\frac{e}{8.5}$

Current in C—A: $\frac{12}{15} \cdot \frac{e}{8.5}$

Current in A—D: $\frac{3}{10} \cdot \frac{e}{8.5}$

$$i_k = \left(\frac{12}{15} - \frac{3}{10}\right) \frac{e}{8.5} = \frac{e}{17}$$

$$r_k = 5.1$$

3) For the actual network the following are obtained:

$$i = \frac{e_0}{6 + 5.1} = \frac{e_0}{11.1} = \frac{e}{37}$$

Complete details of the current distrubution can be obtained, if required, by calculating the difference between the currents obtained from 1) and 2), reducing them in the proportion i/i_k and adding the reduced difference to the currents obtained from 1). For instance, for the conductor C—D, this gives:

from 1) $I_1 = \frac{e}{10} = 0.100\, e$

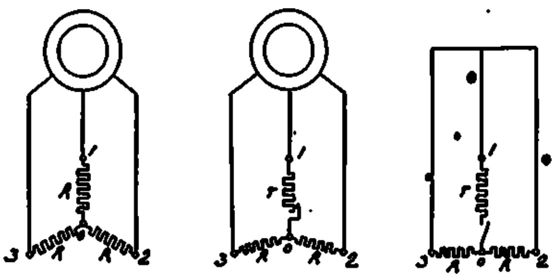
from 2) $I_2 = \frac{e}{8.5} = 0.118\, e$

$I_2 - I_1 = 0.018\, e$

$\frac{i}{i_k}(I_2 - I_1) = 0.008\, e$

$I = 0.108\, e$

d) It has often been proposed to measure the voltage to earth of the neutral point of a three-phase net by means of a potential transformer connected between earth and the neutral point of three other Y-connected potential transformers (Fig. 5 a). In the event of an earth the diagram is as shown in fig. 5 b, which shows at once that the voltage across the neutral point transformer is



a b c
Fig. 6.

$$e' = \frac{Z'}{Z' + \frac{Z}{3}} \cdot e$$

The voltage so obtained accordingly depends on the size of the impedances of the transformers. These in their turn depend partly on the saturation, which can be quite different for the different transformers, which makes any calculation of doubtful value. In addition phase displacements can easily arise, so the arrangement is not one to be recommended. If, however, the three Y-connected transformers are

replaced by a three-phase transformer of the core type the method can possibly be utilized. On account of its design such a transformer offers a relatively small impedance to currents of equal magnitude in each of the three phases, *i.e.* Z is small and e' approaches e.

e) By the connection in Y of three equal resistances (Fig. 6 a) it is possible, in a three phase net, to obtain currents which are proportional to and in phase with the corresponding voltages to neutral. It is, however, sometimes desirable, for example when it is desired to use this connection for a single-phase wattmeter or wattmeter-type relay, to be able to control the size of the current by regulation of of the resistances. It is not, however, necessary to regulate all of the resistances, but is sufficient to regulate one of them (fig. 6 b). The current in this variable resistance can then be easily calculated as follows:

If the circuit through the variable resistance is opened (fig. 6 c), the voltage e_0 between the points 0 and 1 is clearly equal to the height of the voltage triangle, *i.e.*

$$e_0 = \frac{\sqrt{3}}{2} \cdot e$$

where e is the line voltage. It is obvious that e_0 is in phase with and proportional to the voltage to neutral e_1 for phase 1.

If the variable resistance now be connected in, the voltage e_0 will, according to fig. 6 c, cause a current to pass through r which, if the impedance of the source of supply be neglected, can be directly calculated as

$$i_0 = \frac{e_0}{r + \frac{R}{2}} = \frac{\sqrt{3}}{2} \frac{e}{r + \frac{R}{2}}$$

The currents in the two resistances R are of course not in phase with their respective phase voltages, but this is not of importance for the case under consideration.

Ivar Herlitz.

Vesterås, Sweden. 1927. Vestmanlands Allehanda Printing Co.

ASEA-JOURNAL

ALLMANNA SVENSKA ELEKTRISKA A.B.
VESTERAS — SWEDEN

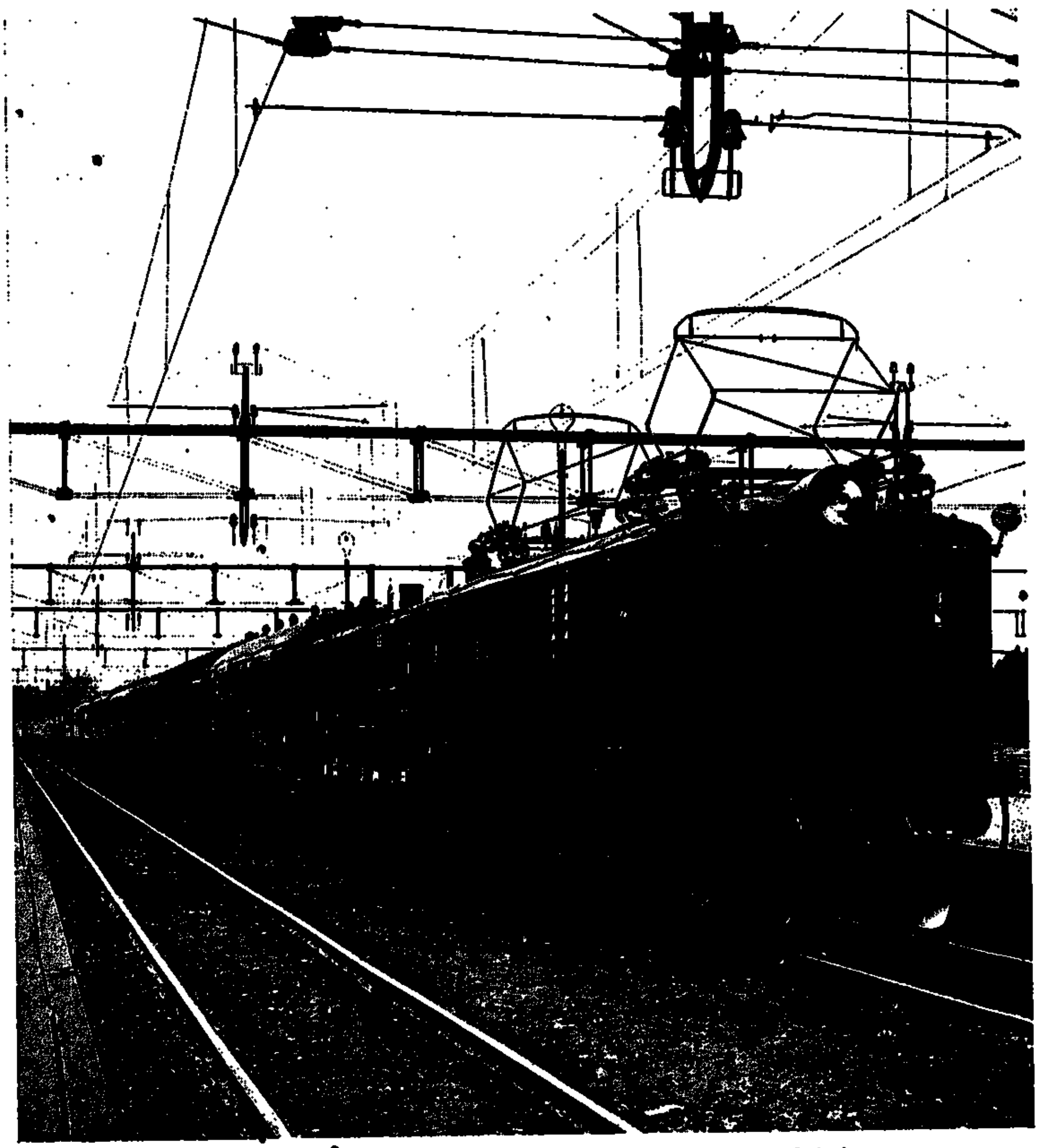
SWEDISH GENERAL ELECTRIC LTD
5. CHANCERY LANE—LONDON

MONTHLY REVIEW

VOL. IV 1927

All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesteras, Sweden.

JUNE-JULY Nos 6-7



Locomotive class D in passenger service on the Swedish Railway Line Stockholm—Gothenburg.

MOTORS FOR "D" CLASS LOCOMOTIVES OF THE STOCKHOLM—GOTHENBURG RAILWAY, SWEDEN.

(Paper read before a meeting of railway engineers in charge of the Stockholm—Gothenburg railway).

Single phase motors have only been used on railway work for a comparitively short time; their introduction and development must be placed exclusively within the present century.

In this article we shall briefly run over the development of the single phase motor — the series motor only — since a review of the difficulties which had to be contended with at first gives a very good idea of the motor itself.

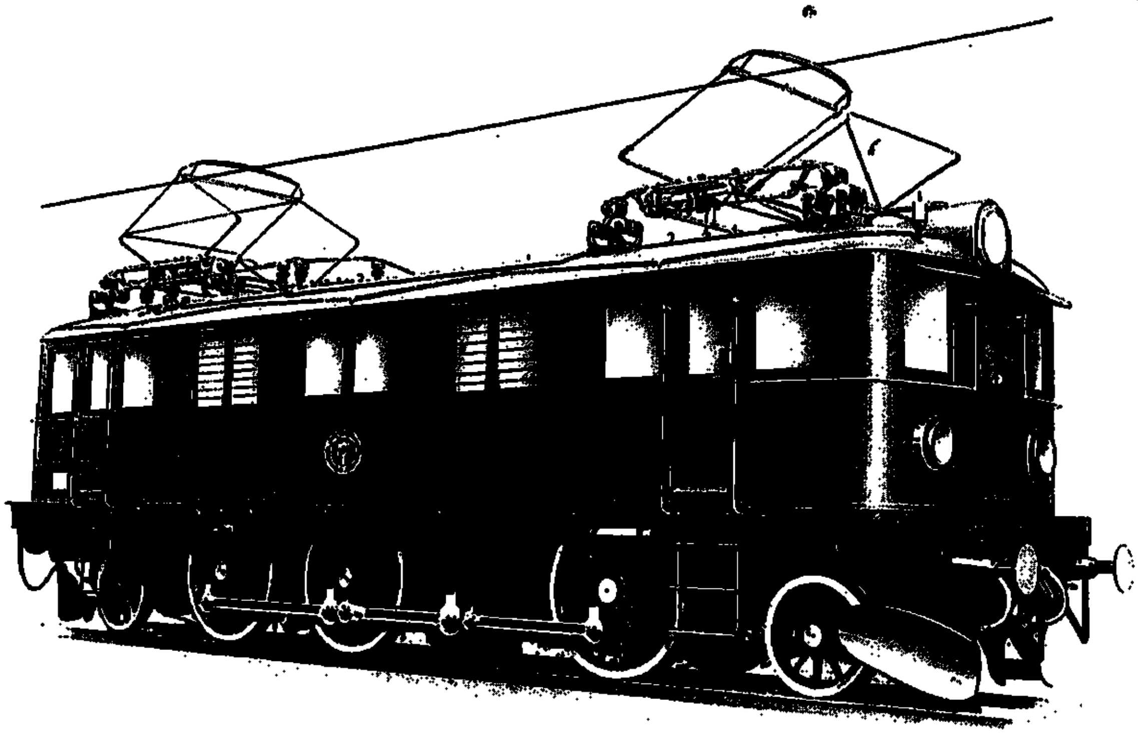


Fig. 1. 1,660 h.p. passenger and goods locomotive class D for Stockholm—Gothenburg line.

That they have reached a high state of excellence in spite of this short period may well be ascribed to the rapid advance which has taken place in electrical machine design in general since experience obtained with one class of machinery can be more or less applied to another class which is, after all, closely allied with it. The fact that D.C. railway motors had been constructed for about 20 years when the first practical single phase motor for railway work was built was of very considerable help, particularly as regards the mechanical construction which was to a great extent quite clearly settled right from the beginning. It was very soon found that as regards the electrical parts considerable departures had to be made from D.C. motor practice, but in spite of this it took an appreciable period, at least 10 years, before the correct principles of construction began to emerge clearly.

At the commencement, it was known that the direction of rotation for a D.C. series motor is not changed when the current supplied to it changes polarity. This idea led at once to an attempt to work such a motor with A.C. and for this purpose the field magnet was made laminated in order to avoid excessive iron losses. A large number of difficulties were, however, encountered, the motor gave rise to an excessive lag in the phase angle and sparking occurred at the brushes to an excessive extent. What were the causes of these faults?

First, as regards the low power factor this was obviously caused by the high self-induction of the motor which, it must be remembered, was made for the first attempts very similar to an ordinary D.C. motor which possesses considerable self-induction, both in the field winding and also in the armature winding. The other

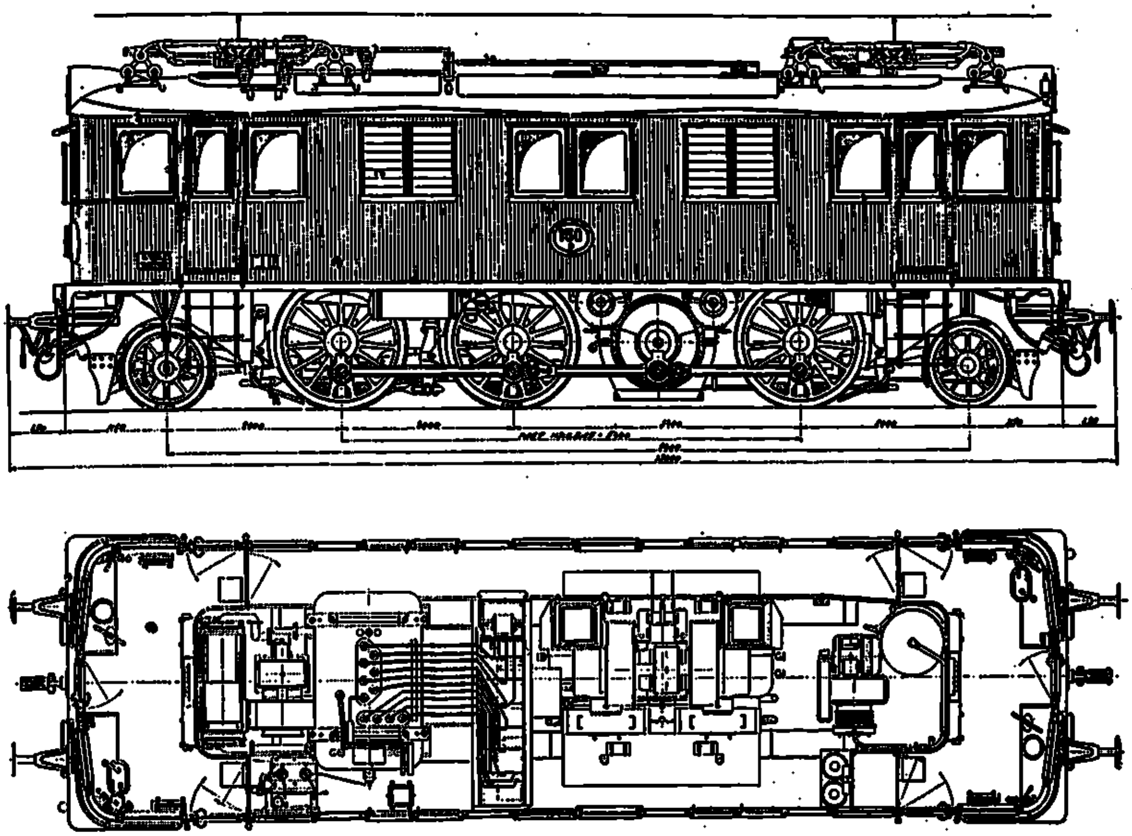
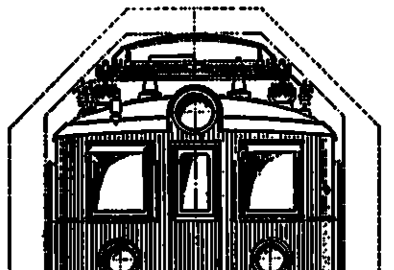


Fig. 2. General arrangement drawing of locomotive class D.



chief drawback, the bad commutation, was caused by the pulsations of the main field giving rise to so called transformer voltages, or more correctly large currents, caused by these voltages in the armature coils short circuited by the brushes, so that every time a segment of the commutator left the brush a considerable current had to be broken giving rise to an excessive spark.

The discovery of a method of overcoming these difficulties, wholly or partially, is due to B. G. Lamme of The Westinghouse Co. who in 1902 was able to announce that he had constructed a practicable series motor for single phase A. C. Lamme's motor embodied the following new features:

1) The self-induction of the armature was practically eliminated by a so called compensating winding, *i.e.* a winding on the poles, co-axial with the armature winding, which by being connected in opposition to the armature winding neutralises the self-induction.

2) By suitable design the number of turns on the magnet poles was reduced to the least possible, thus reducing the self-induction of the field winding.

3) Conductors of high resistance were connected between the armature winding and the risers of the commutator so that short circuit currents in the brushes were reduced to a relatively safe value.

The value of these arrangements can perhaps

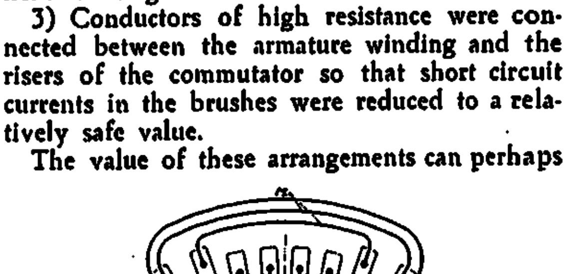


Fig. 3. Arrangement of stator windings in single-phase series motor, type KJ 136.
K = compensating winding. Kp = commutating winding.
M = field winding.

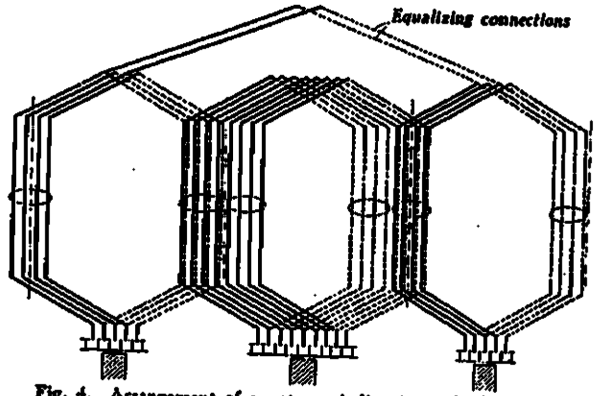


Fig. 4. Arrangement of armature winding in single-phase series motor, type KJ 136.

be judged best if we look forward about 25 years to the present time and see what is now left of them in the single phase motors of to-day. As a modern motor we may well examine the motor which at the moment is of greatest interest, namely that which is used on the locomotives handling traffic on the Stockholm—Gothenburg Railway in Sweden. It will be first noted that the compensating winding is retained and that the field winding has relatively few turns. The high resistance conductors have, however, disappeared and from this it would appear that experience with this arrangement was not altogether satisfactory. Actually what has happened is that, at any rate in Europe, there has been a general adoption of a frequency of $16^{2}/_{3}$ for railway work, which has made it possible to construct motors without such resistance connections and still obtain a motor which does not spark badly when starting. The resistance connections are now practically universally done away with but in their place another idea has been adopted, namely commutating poles. If we look at a modern D.C. machine we find that between the main poles small poles are placed, the function of which is to overcome the self-induction or breaking voltage which occurs when an armature coil, which has been short circuited by a brush, leaves the brush *i.e.* is open circuited. What

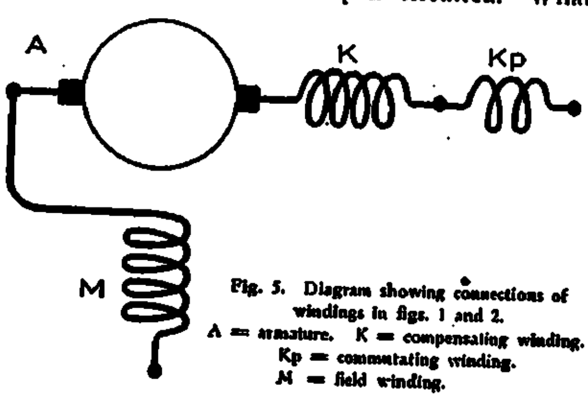


Fig. 5. Diagram showing connections of windings in figs. 1 and 2.
A = armature. K = compensating winding.
Kp = commutating winding.
M = field winding.

occurs is that the current in the coil has a certain direction immediately before the coil is short circuited by the brush and that this direction is reversed after the coil leaves the brush. The reversal of the current is made difficult by the self-induction of the coil and the idea of the auxiliary poles is to induce in the coil such a voltage that the actual break may be sparkless. Precisely the same thing exists with single phase motors but in addition the transformer voltage previously referred to arises so that the commutating poles must also overcome this voltage. Between the transformer voltage and the current reversal voltage there is a phase difference of 90° which means that at the instant when one voltage is zero the other has reached a positive or negative maximum. The commu-

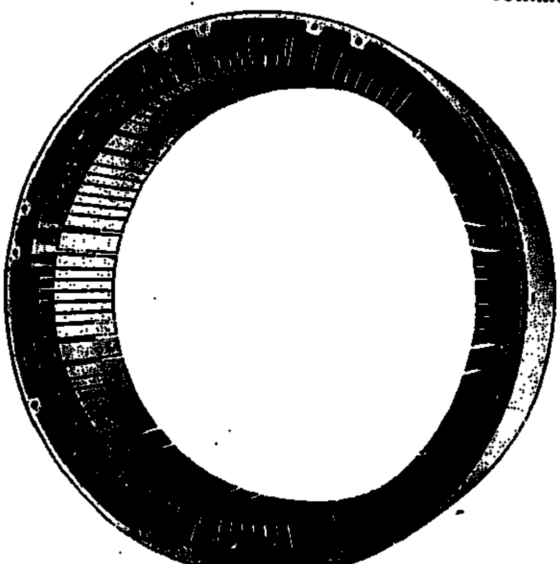


Fig. 6. Finished stator core for single-phase series motor type KJ 136.

tating field must, therefore, have two corresponding components, one in phase with the armature current and one lagging by 90° or otherwise expressed the resultant commutating pole field must lag behind the current by an angle of approximately 45°. For this a special winding for the commutating poles is required and many different arrangements have been tried but it will be found that in the long run only one has survived; this is quite simple and is effected by shunting the commutating pole winding by a resistance with suitable self-induction or very often noninductive.

By this arrangement full compensation for the current reversal voltage, at all speeds, and for the transformer voltage (theoretically) only at certain speeds, and for certain currents, has been obtained. Practically the compensation is complete over a very large range except at

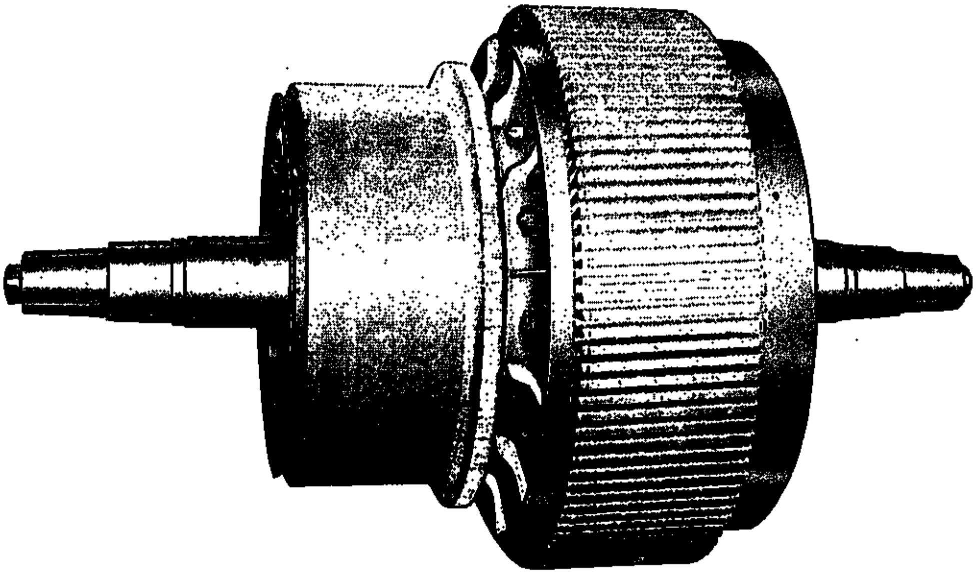


Fig. 7. Finished rotor core with commutator for single-phase series motor type KJ 13o.

standstill where the transformer voltage is entirely uncompensated and we have to depend entirely on the brush resistance. This resistance cannot be allowed to exceed a certain limit, from which it follows that the motor is so constructed that the transformer voltage, although causing a certain amount of sparking during starting, is not sufficiently great to damage the commutator and windings. From what we have said it also follows that it is not to be recommended that the motor should be first held by the brake and full-load current or more allowed to flow.

The stator (fig. 6) for the D class of locomotive motors is built up from insulated rings of sheet steel, 0.5 mm thick (so called dynamo sheet) which are held together on each side by steel press rings drawn together by steel clamps let into the sheet and rings. The rings are machine finished on the outside to exact size so that they fit into the corresponding bore in the housing. The three stator windings, the field winding, the compensating winding and the commutating winding are each placed in their own specially shaped slots. The field and compensating windings are made in coil sections which are finished and bent but not completely insulated and are drawn in through the slot openings, while the commutating winding is wound from wire in a single length *i.e.* a draw-in winding. This last operation is a little difficult but is none the less necessary as the winding only extends over a single tooth on the core and the slots are semi-closed. Each of the stator windings is connected in 12 parallel groups to circular equalizing connections. The insulation on the conductors is of cotton and all windings are insulated against the iron by an insulating material composed chiefly of mica. The finished wound stator is dried and treated with varnish in the ordinary manner. (See fig. 8).

The armature may be considered to be the most difficult part of the motor from the point of view both of manufacture and maintenance. It is clear that an armature built on the same principles as a D.C. armature and running with a maximum peripheral speed under full load conditions of 57 m/sec. must receive all possible care in design and manufacture if it is to withstand the variations in load and vibrations to which a railway motor is exposed. One of the problems for these motors was to obtain the least possible losses in copper and iron as these always increase at the higher speeds and large losses give rise to high temperature rise. This was secured, as far as possible, by a special dividing up of the conductors but calculations showed that in any case the temperature which the machine would reach under conditions of maximum output would be too high for normal insulation. As the temperature could not be reduced there was no other remedy than to make the insulation such that it could withstand the heat developed and on this account a mica asbestos insulation has been adopted. This insulation has been shown by experiment, and also by experience extending over 10 years in other electrical machinery, to be satisfactory up to 150 or 160° and requires very considerable skill in its application if it is to give satisfaction, but if from the beginning a very high standard of work-

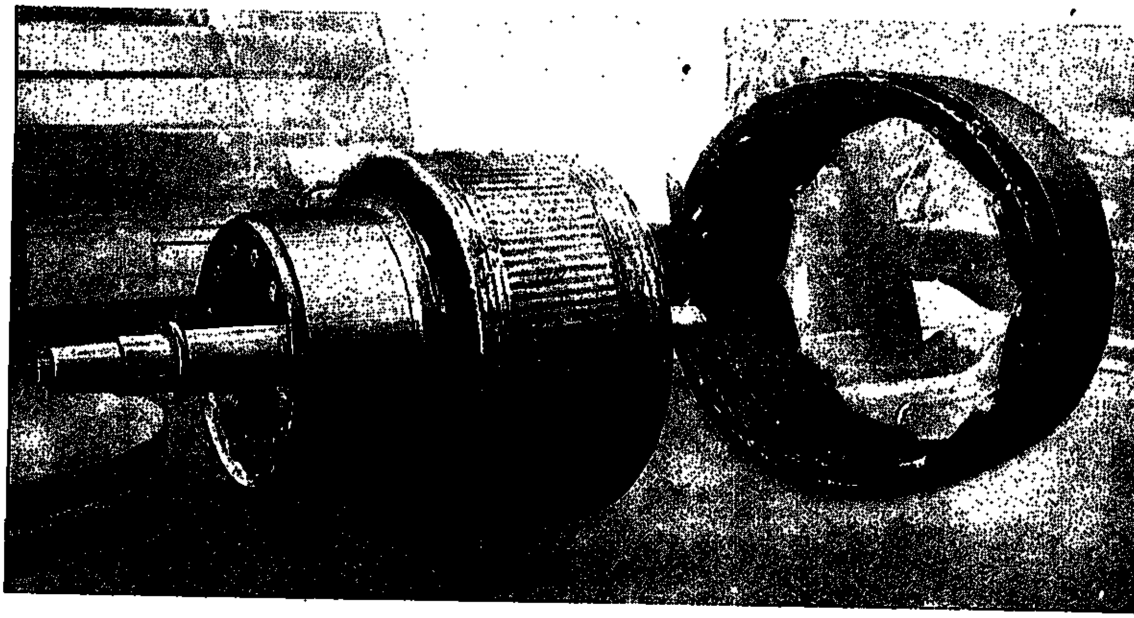


Fig. 8. Completed stator and rotor for single-phase series motor type KJ 136.

manship has been insisted upon the additional costs due to its use need not be excessive.

The armature coils are so arranged that one part which lies at the bottom of the slot is of solid section, while the upper part is divided into three sections crossed over at two points in the slot, so that each section occupies three different positions in the length. By this means the stray currents caused in the conductors by their own magnetic field are reduced considerably. In the lower conductor under all conditions only very slight eddycurrents are induced so that it can be made solid. The upper and lower conductors are joined by a rivet and sweated up, using silver solder. After the copper conductors have been so treated, micanite paper is introduced between each section of conductor in the upper part, after which the whole conductor is wrapped round with a tape of the same material. The four coil parts which lie beside one another in a slot are placed together and the part which lies in the slot is given a covering of approximately 1 mm thick micanite paper insulation which is baked in a specially heated mould so that exactly correct dimensions are obtained. The whole coil is afterwards wrapped round with asbestos tape which has previously been impregnated, after which it is ready for placing on the armature. All surfaces which have to be soldered are of course previously tinned.

As previously mentioned, the armature winding is a typical D.C. winding and may be more exactly described as a parallel winding with 12 parallel circuits. To prevent more or less heavy equalizing currents passing through the brushes in the event of unsymmetrical circuits, there is at the back of the armature an equalizing winding which is connected to every alternate armature conductor and this is also insulated with mica (see fig. 4).

The armature conductors are soldered direct into the segments of the commutator without the use of separate commutator risers. In this way the winding is compact and rigid, easy to protect against damp and dirt, while the points at which the soldering is carried out are surrounded by an adequate amount of copper. This is of importance since, when starting, the local currents which occur might otherwise tend to heat up the soldered joints. A drawback to this type of winding is certainly that not only putting the coils in position, but also the soldering requires the very greatest care and skill on the part of the workmen but as in this case we were aware of the fact and as our workmen are used to carrying out jobs of a similar nature the result has been entirely satisfactory.

The armature core (fig. 7) is mainly constructed in the same way as the stator; the same core plate is used, *i.e.* after stamping the stator rings the centre has been used for the rotor and the rotor plates punched from it. The finished rotor core plates are placed on a steel rotor spider, a sufficient number being used to give the correct length of core. The plates are then placed between two end flanges, of which one rests against the shoulder of the rotor spider and the other, which is placed in position last, is drawn up to the first by bolts. The spider has

Fig. 9. Locomotive class D in passenger service.

a cylindrical extension upon which the commutator is forced.

As regards the mounting of the spider upon the shaft it should be noted that even with the highest torque which can occur, *i.e.* with the brakes full on *etc.*, no movement whatever of the spider, relative to the shaft, can be allowed, and the friction between these two parts must be so great that the spider is absolutely firmly fixed. If any movement should occur from any

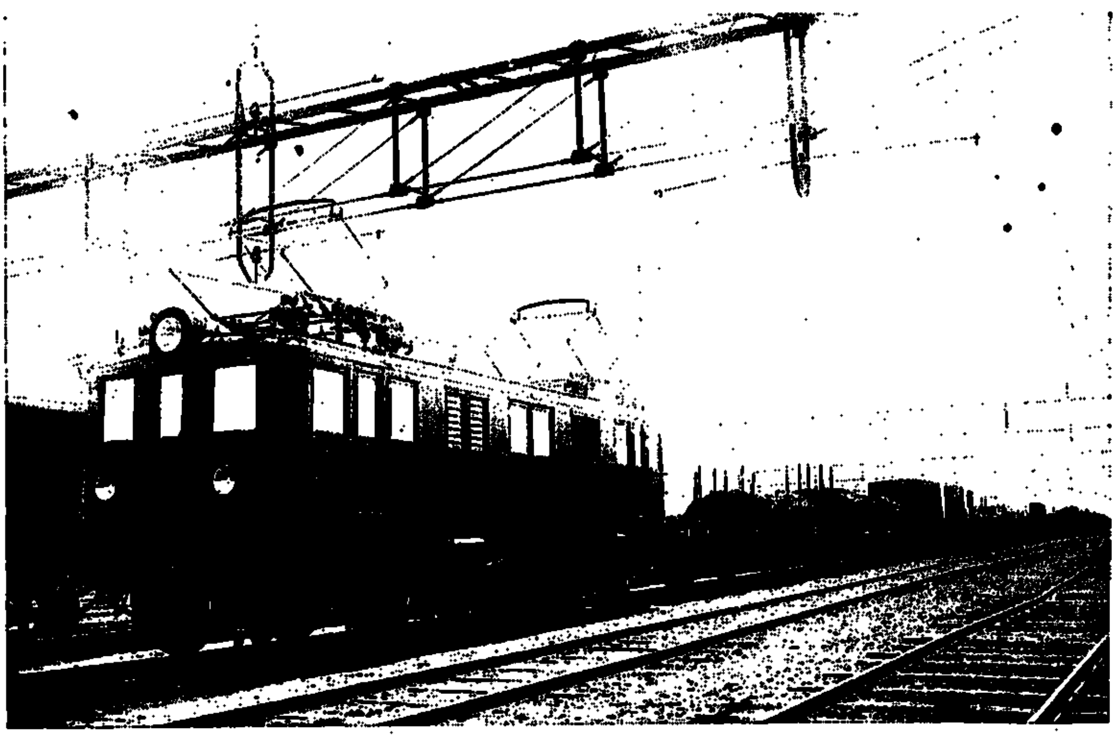


Fig. 10. Locomotive class D in freight service.

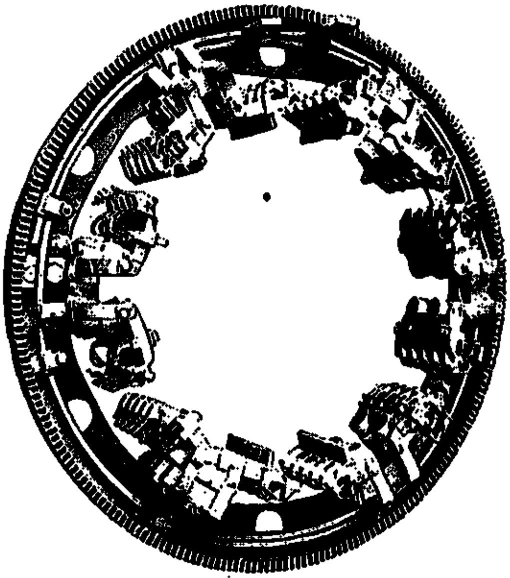


Fig. 11. Brush rocker.

cause, it would be absolutely certain that it would be repeated and would then occur with increasing frequency until the spider became quite loose on the shaft, and a key would not be of any great help but would only serve to lengthen the process a little. Since the spider must be firmly held by friction alone, a key is superfluous and in the case of these motors has actually been omitted. The greatest tangential stress which can occur at the periphery of the shaft is approximately 18 tons (when pulling up the engine) and the pressure used for forcing on the spider is approximately 160 tons *i.e.* a stress of 160 tons at least at the shaft periphery is necessary to turn the spider on the shaft and this figure represents a satisfactory factor of safety.

The commutator consists of hard drawn copper having a hardness number between 90 and 100 and the insulation is as usual of a mica preparation. The assembled clamps are subjected to a special treatment before the commutator is machined and this, together with the treatment as a whole, ensures that the commutator is able to withstand the highest temperatures occuring in practice without any measurable deformation. In general, no departure from the circular form exceeding 0.02 mm has been observed and this magnitude lies well within the limits of accuracy for such a part. The mica is scraped from between the segments of the finished commutator so that it lies about 1 mm below the surface. This operation must be done exceedingly carefully so that, for example, no mica is allowed to remain between the edges of the segments: these finally receive a light grinding and polishing, intended to remove all roughness. Scraping, carefully carried out, helps considerably in giving the commutator a long life but if badly done gives rise to rapid spoiling of the wearing surface with the result that the motor must very soon be overhauled again.

An important detail is the brush gear, together with the brushes. These have to convey current to the armature with as little disturbance as possible, *i.e.* they must be able to allow the brushes to adapt themselves to the commutator surface without difficulty. In allowing this there must, of course, not be excessive brush preasure which would give rise to high friction losses, and consequently a hot commutator. To ensure that the brushes will follow the commutator surface and accomodate themselves to small inequalities without employment of excessive brush pressure, we have adopted a brush holder with double springing, having a movable intermediate piece having a certain mass. For conducting the current from the brush to the bus conductors through the brush holders a special carbon clamp is used which closely resembles an ordinary knife contact. The carbon clamp is insulated outside with fibre and a flexible tail with a cable socket is riveted to it. The other end of the flexible tail is terminated by a plug contact which is placed in a corresponding spring socket in the brush holder. The current handled by each brush is fairly high and it is accordingly of great importance when assembling that the brush clamp is firmly fixed on the brush, since otherwise the heat developed at the contact surface would rapidly destroy the temper of the metal and the clamp would become loose or be burnt.

The brushes deserve a special chapter to themselves. After many years of experiment in many directions, we finally decided on a carbon containing a considerable amount of graphite, which is produced by heating ordinary carbon in special electric furnaces. These brushes have

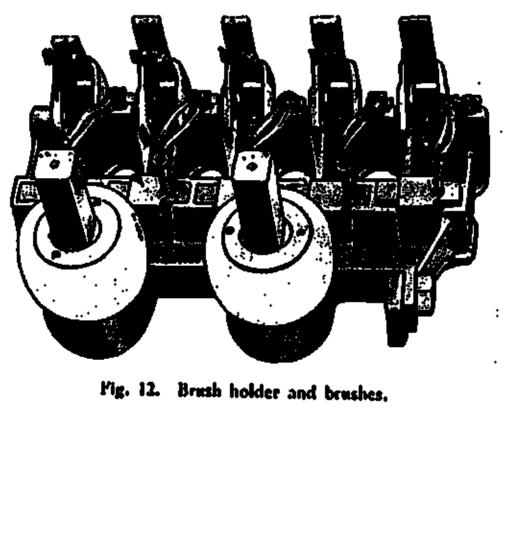


Fig. 12. Brush holder and brushes.

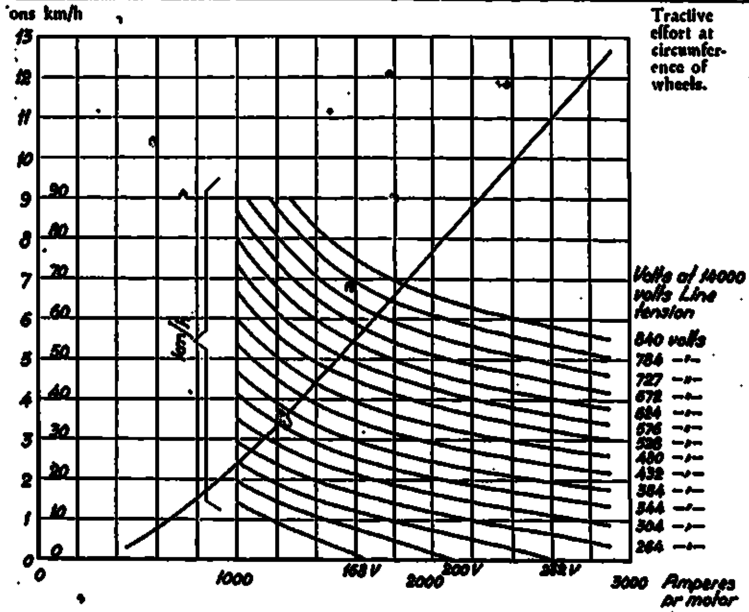


Fig. 13. Railway motor type KJ 136 for passenger service. Gear ratio 1:3.2.

the characteristic of being good conductors of heat, so that a relatively large amount of the heat which is developed at the contact surface is rapidly conducted through the brush to the brush holder, from which it can be dissipated by means of the cooling air. A requirement for a good railway motor brush is that it shall have a certain contact resistance since, as previously pointed out, the contact resistance is all that limits the short circuit currents caused by the transformer voltages arising during starting. On the other hand, if this contact resistance should be too high the losses during normal running, and due to the ordinary working current, would be unnecessarily large so that the resistance referred to must be kept within certain definite limits, determined by experience. It has often been found that brushes after a relatively short time in use, begin to break up, and the reasons for this have been a little obscure, since in many cases the load has been small. The explanation, however, is that many grades of carbon brush when running at no load have the property that the coefficient of friction rises to an abnormally high value so that both commutator and brush are heated up by the frictional losses to such an extent that the brushes begin to fall to pieces. Accordingly, for a good brush it is necessary that even when running for certain periods at no load the coefficient of friction will not rise to any dangerous extent and what may be considered as dangerous must be determined by experiment in each particular case. We have found that the coefficient of friction when testing in the special machine in our laboratory should not increase much over 0.2 or 0.25 at no load.

The bearings are constructed with bearing housings and bearing shells which are both divided. For lubrication fresh oil is used supplied direct from a Friedman lubricator, and further at the bottom of each bearing is a felt pad provided with a wick for feed, and this may be regarded as a safety device to meet the possibility of the lubricator not starting to work instantaneously. An oiling system with separately driven lubricators has been chosen since experience has shown that railway motor bearings are better lubricated with fresh oil than with circulating oil, which method is usually employed for ring oiling bearings. With such a system it is impossible to prevent dust from gradually becoming mixed with the oil and as this continually passes through the bearing, the result is that the dust particles are left behind and cause rapid wear of bearing shell and shaft journal.

Motors for such a large output as those in

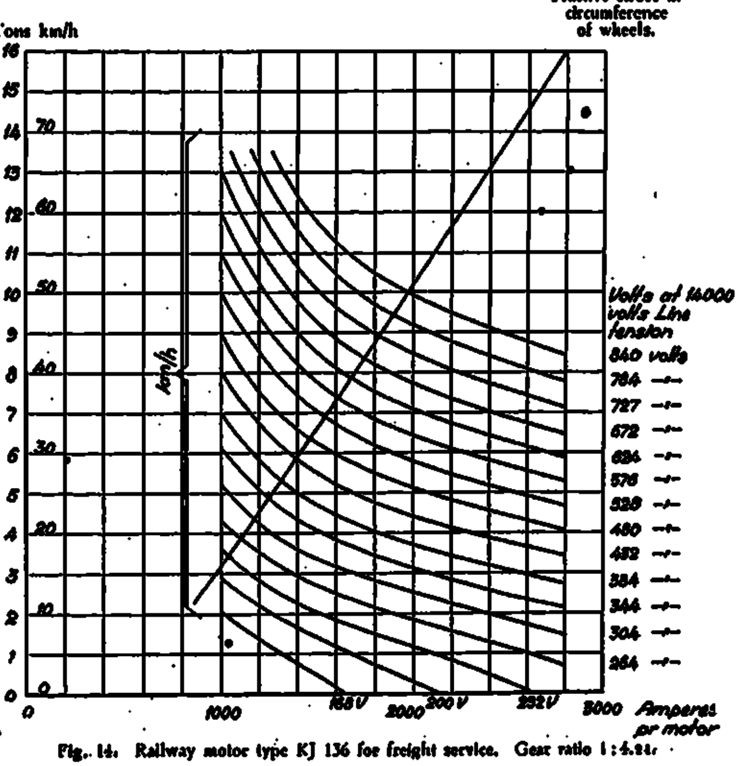


Fig. 14. Railway motor type KJ 136 for freight service. Gear ratio 1:4.21.

question, namely 830 h.p. at 730 r.p.m. and of relatively small dimensions must naturally, be provided with arrangements for forced cooling and this is provided by a separate fan unit carried on the motor frame. Each motor has its own fan and the two fans are driven by a common fan motor which is also a series motor with windings arranged very much as in the case of the main driving motors.

The ventilation is arranged as series ventilation *i.e.* the air is first forced over one end of the stator and from there is led over the stator iron out over the commutator and is returned through the inside of the armature out to the open air through air ducts. The cooling of the armature is thus to a great extent dependent on cooling from the inside of the core and this method has been shown to be exceedingly effective. It also has the advantage that the windings can be completely enclosed, which is particularly valuable as these rotors quickly become covered with coal dust, *etc.*

The performance of a D class locomotive used for passenger service can be gathered by the curves in fig. 13. With 390 volts per motor the machines can develope for one hour a total tractive effort of 6.8 tons at the periphery of the wheels without the maximum temperature rise in the windings exceeding 100° for the rotor and 70° for the stator, and with the same temperature rise they can continuously give approximately 4.8 tons. The corresponding speeds are respectively 65—75 km/hour, the maximum running speed being 90 km/hour. Starting cold, the machines can give approximately 10 tons tractive effort at about 58 km/hour for 1/4 hour. The maximum starting effort is about 12.5 tons. To be able to judge how an electric locomotive is fitted to deal with a certain train, in accordance with a given time table, it is necessary first to have a load diagram for the motor *i.e.* a diagram showing how many amperes the motor takes allowing different times for running a given distance. From this we have to calculate how the temperature rises with the different times in order to determine when a maximum temperature rise will be reached and what this temperature rise will amount to. Several running diagrams of this nature have been made for the Stockholm—Gothenburg line and they have all resulted in an estimate for the greatest temperature rise in the armature winding somewhere between 90—100° thus a value which is quite allowable. This corresponds to an express passenger train weighing approximately 500 tons.

It is possible that the present article, which has described the development of the motors and the difficulties encountered, may give the impression that the locomotives which we are especially considering are somewhat delicate things and costly in maintenance. This is actually far from being the case but when handling these machines, which differ so considerably from the steam locomotives formerly in use, it is necessary to start on a correct basis. If this is done there is no doubt that the maintenance costs will be exceedingly moderate so that the arguments which now exist for extended electrification of the State Railways, and other privately owned lines, will be further strengthened.

Since this paper was prepared the locomotives for the Stockholm—Gothenburg railway have been in regular service for nearly two years. During that time the reliability of the motors as well as of other electrical and mechanical parts has been clearly established and it is not too much to say that all calculations and estimates agree very well with figures found in practice. Although it may be too early to judge the maintenance costs, experience has shown so far that these are very moderate, which is the more noteworthy from the fact that the operation and maintenance of the electric material from the beginning was taken over by the old staff, which for natural reasons could be given only a short training before being placed in charge of the electric service.

SWITCHGEAR OF CLASS D LOCOMOTIVES FOR STOCKHOLM—GOTHENBURG LINE.

When the power of an electric vehicle is very high, as in the case of an electric locomotive for use on a main line railway, a simple controller handling the main current, as commonly used on tram cars, is no longer suitable for operation. The regulation of the motor current, in the case of large locomotives, is usually carried out indirectly by contactors.

The switchgear equipment of the locomotives for the Stockholm—Gothenburg line includes a large number of separate pieces of apparatus. The main part of the equipment is made up of the motor contactors mentioned above, which are 18 in number and are used to supply the motors with the desired voltage.

To this must be added gear for the motor and transformer ventilators, compressors, train heating apparatus, overload relays, lighting changeover switches, air pressure governors and pneumatic circuit breakers, brake valve with time delayed connection, certain drum switches for various apparatus, control cutout, current and pressure transformers and a panel with fuses. All these various items are collected together and mounted upon a common framework.

Beyond the above apparatus frame, we have the oil switch and near to this the short circuiting arrangement. further parts are the reversing switch, the controllers (one in each driving cab), a valve for closing the oil immersed circuit breaker, and, in each driving cab, a lighting panel. The last is made up of fuses and switches for lighting and heating. Lastly, in each driving cab are two ammeters and one volt meter.

A battery for emergency lighting is housed in the machine room. On the roof are mounted the current collectors, two isolating switches, two air and one high tension leading through insulators, and two head lamps, one at each end. Under the locomotive are the electrical connections for the control current, the train heating and testing. In addition, at different parts of the locomotive are placed terminal boards for joining up the various circuits. Beyond these there are also some resistances for heating and several lamps and plug contacts.

If the connection diagram, fig. 1, is referred to it will be possible to see how the different parts are connected together.

The current is taken from the overhead contact line by the collector, and passes through the high tension leading through insulator, and through the main oil switch to the high tension winding of the transformer. The voltmeter in the driving cab indicates that pressure is on the transformer. The next operation is to put the reversing drum of the master controller in the forward or reverse position. This operation causes several connections to be made simultaneously. Control current is transmitted to one of the operating coils of the reverser, corresponding to the desired direction of running. The ventilators and compressors receive current through their respective contactors. The coil of the heating circuit contactor may also be energised. There are interlocking devices between the main controller drum and the reversing drum, and between the reversing drum and the push buttons, which serve to give remote operation of the main oil switch.

Everything is now ready for starting the locomotive. This cannot be done unless the reverser is in its proper position. An interlock ensures that the operating coil of the ventilator contactor is not energised until the reverser is properly closed in one of its positions. The control current flows from F or B to the reverser finger N and from there to the ventilator contactor. Auxiliary contacts on this relay connect the return conductor for all the main contactors to earth, and it is only now possible to close the main contactors when voltage is applied to their operating coils from the controller. It will thus be seen that the ventilator contactor also acts as an interlocking relay, although this is not its only auxiliary function. The current in the coil of this contactor is also passed through the overload relay in the motor circuit so that in case of excessive current in the motor circuit the motor contactors are released. The ventilator contactor serves further as a no volt relay. This means that an interlock is provided which makes it impossible to close the contactor in any controller position, but when a new start is made and the main contactors must be closed one after the other, beginning with Nos. 1 and 3. The operating current for the coil of the ventilator contactor is accordingly taken through contacts and segments in the first position ($^1/_2$) of the controller and in the zero position. This arrangement of the conductor has the further function of preventing overload release in the motor circuit and release by the pneumatic switch in the first position ($^1/_2$) of the controller. As will be seen from the diagram, the return conductor J_2 runs from the coil of the ventilator contactor direct through the contacts of the main and reversing drums of the controller to earth. This arrangement has been adopted to facilitate

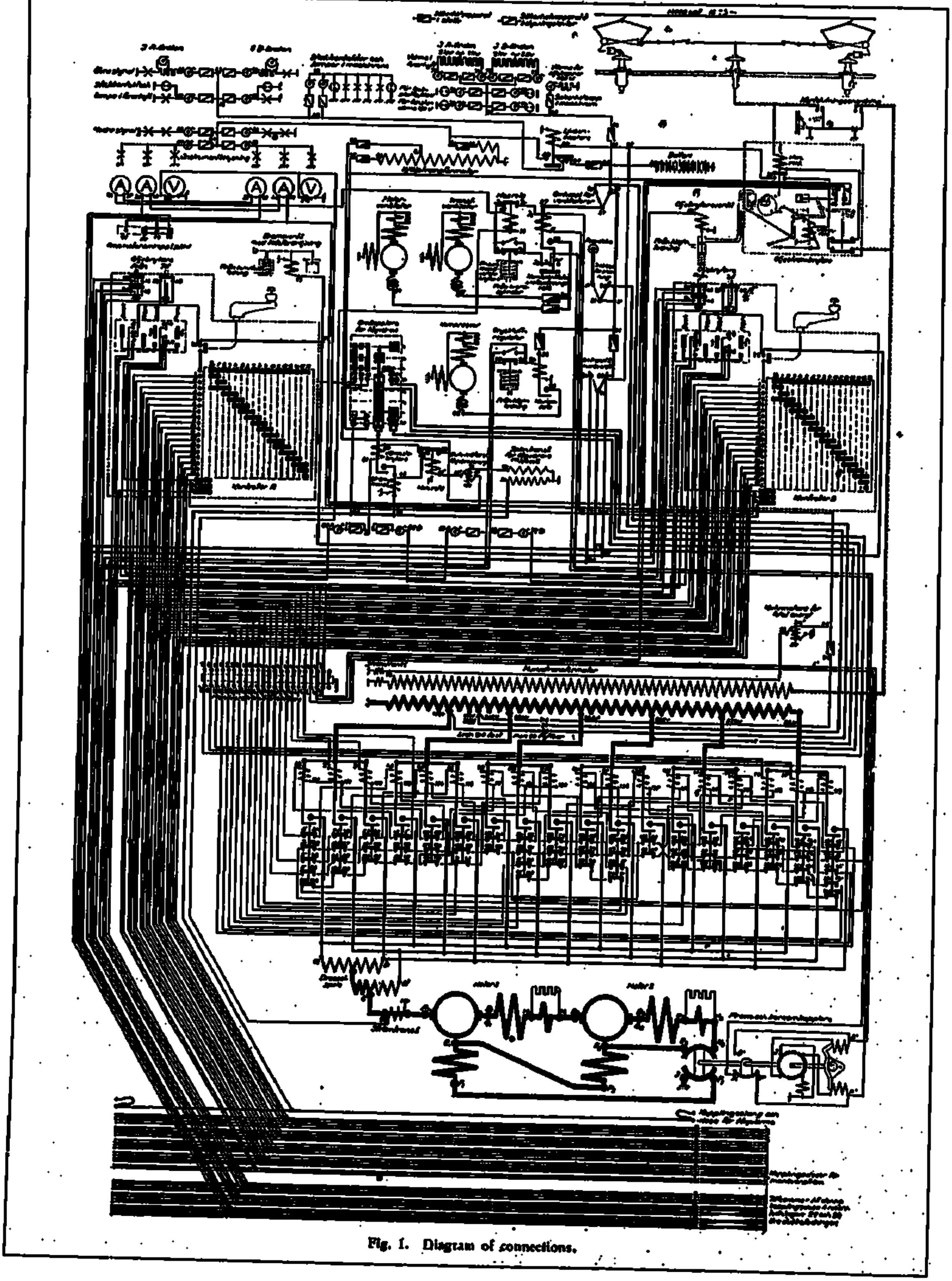


Fig. 1. Diagram of connections.

Fig. 2. High tension leading through insulator.

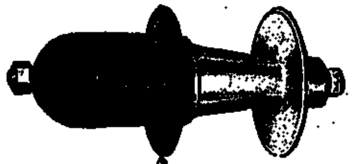


Fig. 3. Insulator for compressed air supply.

operation when the locomotive is used for shunting purposes. By releasing the handle on the controller (dead mans grip), the motor current can be broken. This button is connected with a sliding contact in the controller, through which the supply of operating current to the motor contactors is lead. If this is used, the no volt relay does not act but still reconnection of the operating current can only be made in the zero position. In all other positions reconnection is prevented by a mechanical interlock in the controller. Thus, if the ventilator contactor is closed we can begin to run. In the first position ($^1/_4$) of the controller, contactors 1 and 3 are closed and the motors obtain current from the 168 volt tapping on the low tension winding of the transformer. Due to the effect of a choking coil, the voltage which is supplied to the motors is, in this position, rather less than the pressure at the transformer terminals. The current passes through the rotors, compensating and commutating windings, through the reverser to the field windings and from there returns through the reverser to earth, and from there back again to the transformer through the earthed end of the transformer winding. Depending on the position of the reverser, (forward or reverse), current is supplied to the field windings in one direction or the other, and the rotors turn in the forward or reverse direction. The controller may be turned further, step by step, thus supplying to the motors the voltage which is required to give the desired speed. The function of the choking coil is to divide the voltage between the transformer tappings and to obtain transition between transformer tappings without current interruption. The motors are thus supplied not only at the voltages of the transformer tappings but also at two additional values of pressure between each tapping, altogether 16 steps being available.

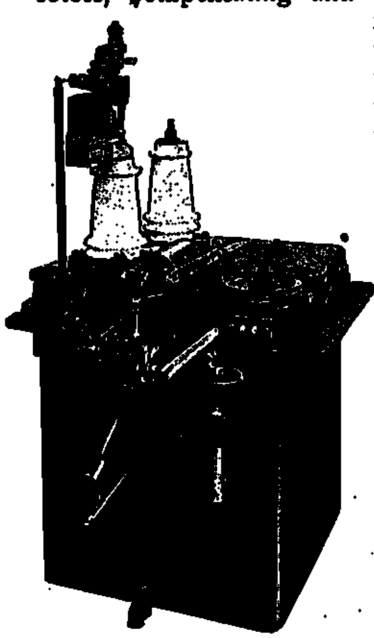


Fig. 4. Oil switch.

The interlocking contacts which are fitted on the contactors and operate simultaneously with the main current contactors, are intended to interlock the contactors, which should not close together and prevent short circuits between transformer tappings and overloads on the choking coil.

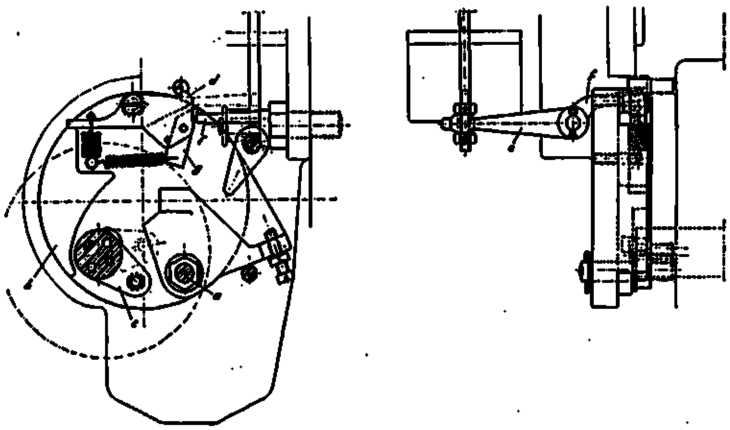


Fig. 5. Release mechanism of oil switch.

The interlock provided differs from that fitted to earlier locomotives (classes Od, Pb and Of) in that at least a proportion of the return leads of the contactors are interlocked alternatively, progressively or retrogressively. In this manner the contactors are combined in small groups with a common interlock between them connected in a definite manner. In this way the total number of interlocking contacts is reduced and at the same time the distribution of the interlocking contacts is more even.

A point of great merit about the new arrangement of interlocking is that by altering the number and kind of the groups (odd or even groups) the distribution of the auxiliary contactors can be altered practically at will. This effects the method of interlocking in general. The object of the interlocking is, of course, to prevent two contactors in the same combination being closed

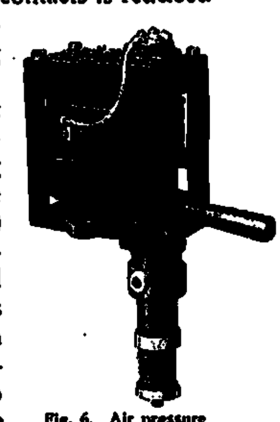


Fig. 6. Air pressure governor for oil switch.

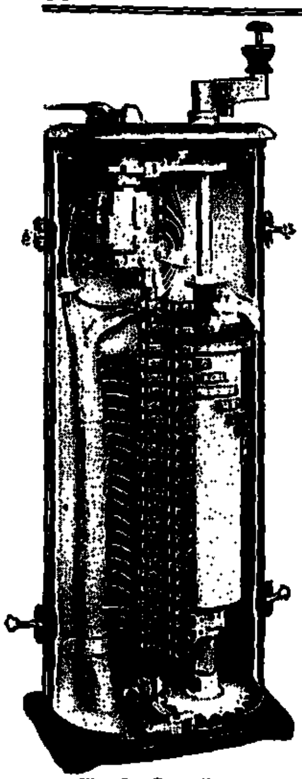


Fig. 7. Controller.

together. Such contactors are always three which fall in order, i.e. 1, 2, 3—2, 3, 4—3, 4, 5—4, 5, 6. The interlocking contactors are partly placed in the leads to the operating coils and partly in the returns. All contactors which only provide interlocking for a definite contactor over one or several others have been placed in the supply lead to this particular contactor and have been designated with the number of the operating lead (controller lead) with an index, e.g. 6' — 6 A — 6 B — 6 C.

The interlocking contacts which interlock several contactors in common over several others must of necessity be placed in the return conductors. These are only designated by figures beginning with 101 so as to denote clearly their general character.

The conductors in the above case are divided into four groups.

The first group, contactors 1—6, in the return conductors are interlocked only progressively over 5—18 (contacts 101—114). The fourth group, contactors 13—18, in the return conductors are interlocked only retrogressively over 14—1 (contacts 115—128). The return conductors to the contactors of the second group (7, 8, 9) are first interlocked retrogressively from 5—1 (contacts 130—134) and then progressively from 12—18, the progressive interlocking being effected through the existing contacts 108—114 which belong to the progressive interlocking of group 1.

The contactors 10, 11 and 12 of the third group are interlocked in the return conductors, first progressively from 14—18 (contacts 136—140) and then retrogressively through the existing contacts 122—128 on contactors 7—11, belonging to the retrogressive interlocking of group 4. As will be seen, all leads to contactor coils pass from the controller through an operating current

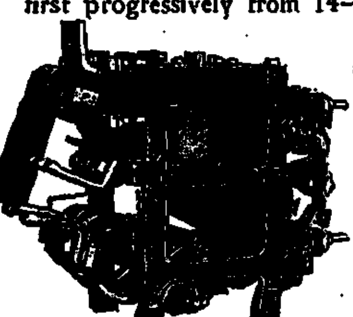


Fig. 8. Motor contactor.

disconnecting switch. The object of this is to disconnect the operating system of the locomotive in case of a fault in either motors or transformer when two locomotives are being worked together (multiple unit connection). If two locomotives are not to be worked in parallel this can be dispensed with.

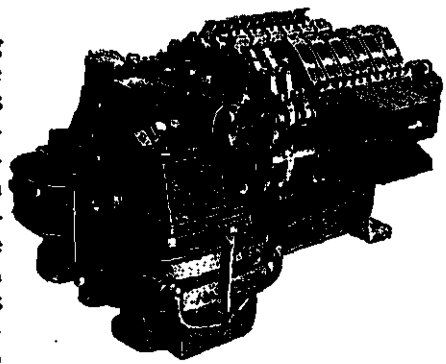


Fig. 9. Reversing switch.

The operating systems of the locomotives are connected with one another by train line receptacles and jumpers. The heating circuit is carried by a separate bus line. The current for train heating is supplied to this through the heating changeover switch in conjunction with a special contactor. Three different voltages can be used for heating, depending on requirements. The heating changeover switch has three different positions marked 1, 2, 3. Position 1 gives the least voltage and position 3 the highest. There is, in addition, a position marked S for shop use. When running the locomotive in or out of repair shops or engine sheds it is possible to run it with the switch in this position, current being supplied through the heating circuit jumper. The heating contactor can only be closed in this position when the main oil switch is out so as to prevent the overhead collector being charged. In the heating current circuit there is an overload relay, over the contacts of which the operating current is taken so that it is broken on excessive overload.

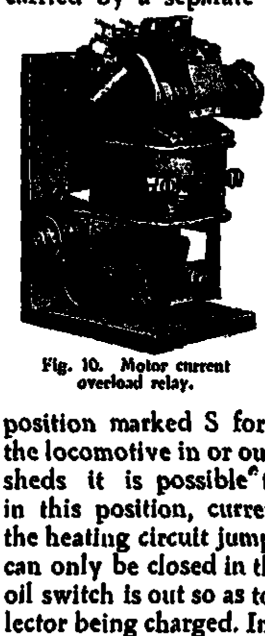


Fig. 10. Motor current overload relay.

The operating current for the compressor contactor passes through the air pressure governor, which makes contact with 6.5 and breaks with 8 kg per cm². An apparatus of similar appearance is used in the conductors to the ventilating contactor. This breaks the supply current to this contactor and in this way interrupts the supply of cur-

Fig. 11. Heating circuit overload relay.

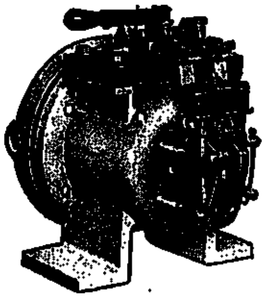


Fig. 12. Air pressure governor.

rent to the driving motors if the brake is applied without first cutting off the motor current. The apparatus (pneumatically operated circuit breaker) operates with a pressure in the brake pipe as low as 0.5 kg/cm². There is further an auxiliary transformer which delivers current to the heating contactor with current supply to heating coupling and also for lighting. When the pressure fails in the overhead line the lighting circuits are supplied from a battery. Changeover from one system to the other is carried out automatically through the lighting changeover switch. There are in addition three other changeover switches. The uppermost connects the ventilators to two different voltages, the middle one changes over the operating system from the main transformer to the testing plug and the lowermost is arranged for operating current supply. If when running two locomotives in parallel the transformer in the leading locomotive is not available for use operating current is obtained from the rear locomotive through the last mentioned changeover switch. Like the operating current disconnecting switch, this changeover switch can be dispensed with when parallel working is not in question. All drum type changeover switches are interlocked with the reversing drum of the controller through the reversing handle. In this way it is ensured that all changing over is done only without current on.

The brake valve with delayed action applies the brakes to the locomotive when the overhead line wire remains dead for more than 30 seconds. The effect of this is to bring the train to rest if the pressure on the overhead line wire fails.

After the above description of the connections we will now turn to the actual apparatus.

For all apparatus for railway work, reliability is of the greatest possible importance. Even minor faults may cause considerable interruptions in the timing of trains. The greatest possible care in construction, manufacture and erection is accordingly of first consideration.

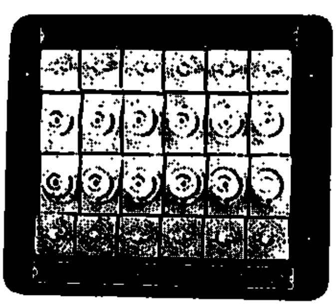


Fig. 13. Lighting panel.

The special considerations have given rise to special designs for all the apparatus used, *e.g.* magnet cores of operating solenoids are pivoted instead of using those of the parallel sliding design, wide bearing surfaces are used for these and for all moving parts, and breaking contacts with rolling contact surfaces are used in conjunction with the greatest possible pressure so as to prevent the contacts becoming welded together.

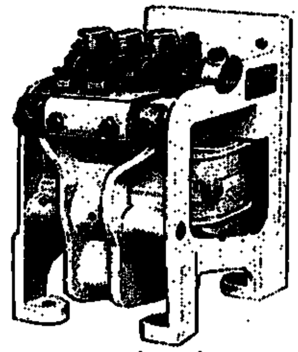


Fig. 14. Lighting changeover switch.

All other contacts are also of the sliding type so as to maintain clean contact surfaces and to ensure certain contact under all conditions. Contact fingers with spiral springs are used in most cases.

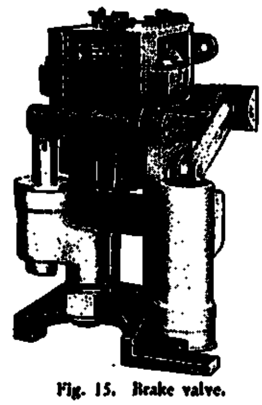


Fig. 15. Brake valve.

Interchangeable unit construction is adopted to the greatest possible extent. The particularly heavy type of interlocking contact is used even for other apparatus, as can be gathered from the various illustrations. Controller fingers are used as operating contacts for the reverser. Bolts insulated by bakelite paper are largely used in the construction.

In going more closely into the design of the separate pieces of apparatus we begin at the high tension side. Fig. 2 shows a leading through insulator and fig. 3 a air pressure insulator. The same insulators are used for both pieces of apparatus. The main oil circuit breaker, fig. 4, differs only from the standard type in the following respects. The arrangement adopted prevents the locomotive circuit breaker from dealing with direct short circuits or with overloads of corresponding magnitude, and works in the following manner.

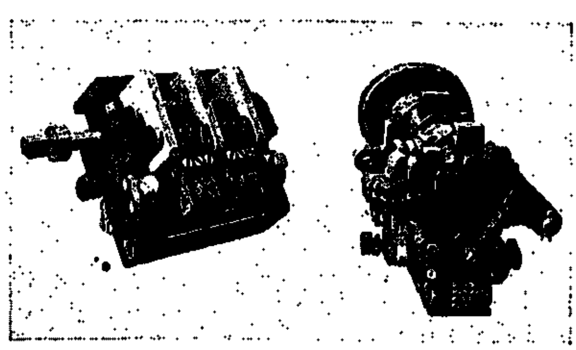


Fig. 16. Drum changeover switch.

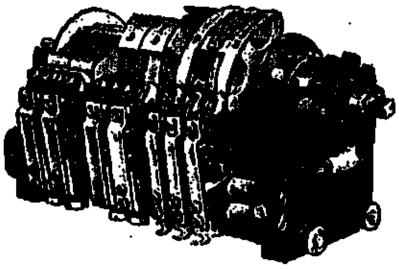


Fig. 17. Heating changeover switch.

From the current collector, the current is taken through the coil of the overload relay and the oil switch contacts to the high tension winding of the transformer. From the low tension winding of this transformer, operating current is taken from tapping 20 through a switch and operating current fuse to point 22. From this point, pressure is taken over the overload relay contacts to the releasing relay. The core of this coil acts direct upon the release mechanism as will be seen clearly from the connection diagram.

When a dead short circuit occurs within the circuit protected by the main oil switch, either in the transformer itself, in the motors or in the conductors to these, the voltage of the transformer falls to zero or practically to zero. The releasing relay is under these conditions unable to trip the oil switch, although the overload relay contacts may close. The circuit must, under these conditions, be broken by the circuit breakers at the substation. As far as this goes, we have the same arrangement as in the locomotives of class Of.

For the new locomotives for the Stockholm—Gothenburg line, an arrangement has been adopted which gives a mechanical trip to the circuit breaker as soon as the short circuit has been broken by the breakers at the substation. Fig. 5 shows the mechanical break arrangement in the normal position with the oil circuit breaker connected.

The arrangement consists of a sector shaped weight *b* pivotted round the point *a* which is lifted by the arm *c* when the breaker opens, and is held in this position by the pawl *d*. When the armature of the overload relay is attracted the release arm is turned so that the part *f*, which is rounded off, can pass over the pawl *g*. As soon as the line circuit breaker is opened and the overload relay has no current passing through it, the release arm returns to its original position and re-engages the pawl *g*, which in its turn acts upon the pawl *d* so that the weight is freed and the circuit breaker is tripped. The main oil switch can be closed by hand, by hand operation of the air pressure valve (fig. 6) or by remote control of this valve by the push button on the controller cover. Break can be carried out by hand, either by remote control through a push button on the controller cover or automatically as described above.

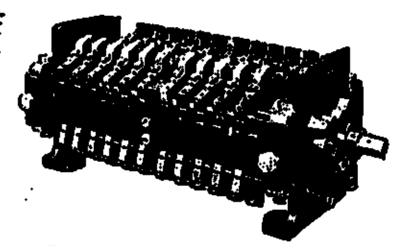


Fig. 18. Control circuit disconnecting switch.

Fig. 7 shows the controller Rigid hinged fingers are used as contact fingers for the main drum. The usual interlocking arrangement is provided between the main drum and the reversing drum, so that the main drum cannot be moved if the reversing drum is in the neutral position and the reversing drum cannot be turned if the main drum is in any other position than the starting position, *i.e.* if there is no current in the motors. In addition there is mechanical interlocking of the push buttons for opening and closing the main oil switch; the push buttons cannot be depressed with the reversing drum in the neutral position. The oil switch can accordingly only be operated from the particular controller which is in use for driving the locomotive.

Fig. 8 shows one of the motor contactors. These pieces of apparatus are designed for continuously handling the large currents for the driving motors

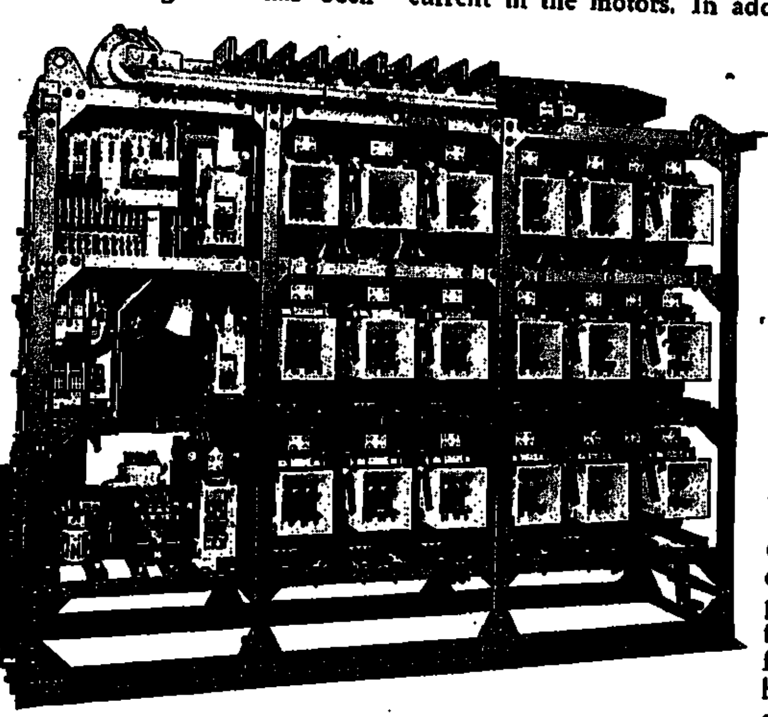


Fig. 19. Apparatus frame, front view.

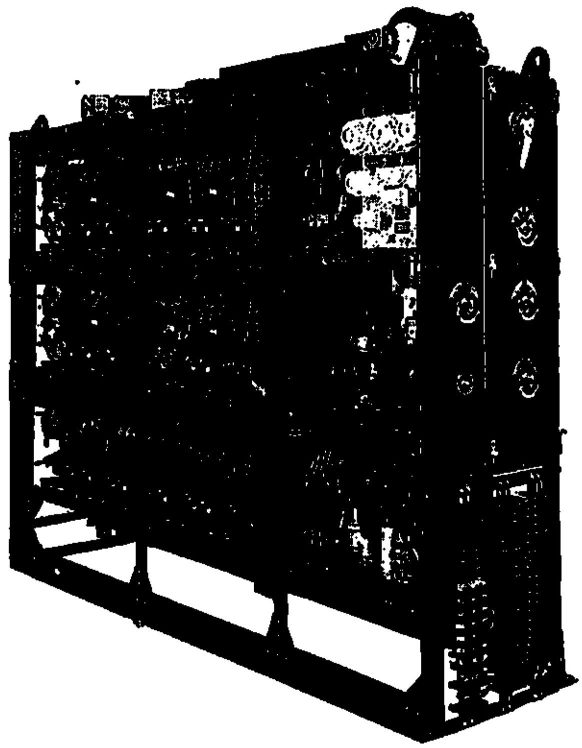


Fig. 20. Apparatus frame, rear view.

and work under more difficult conditions than any other part of the locomotive equipment. These, as well as the other contactors, have been designed having regard to the great voltage variations which occur, a problem which has given rise to various difficulties in construction. This requirement, in conjunction with the great weight of the contact arm, necessitated by the high current, and the necessary heavy contact pressure, has largely determined the construction to be adopted. A design in which the weight of the contact arrangement and the contact pressure act directly on the core of the operating magnet would be less suitable. The reason for this is to be found in the rather poor tractive characteristic of a single phase solenoid.

We must deal a little more closely with the solenoid as this is an important detail of all electro magnetically operated single phase apparatus. The core must be laminated in order to keep down the iron losses. In spite of this the magnet is rather noisy and, at the same time, the tractive effort is low. The reason lies in the sine form of the current. The current and, consequently, the tractive effort change 33 times per second from zero to a maximum value, and back to zero again. If the current is zero the tractive effort is also zero and the solenoid will drop out. But before this has happened, the current has risen again and the solenoid will be reattracted. It is this variation in the attraction which gives rise to vibration and noise. This is prevented by the provision of short circuited windings placed upon the magnet cores close to the surfaces which are in contact. The primary magnet field caused by the current in the main coil, generates a current in the short circuited windings which lags in phase behind the primary current. This secondary current gives rise in its turn to a magnetic field which has the same phase lag behind the main field as the lag of the secondary current behind the primary current. Instead of one field we accordingly have two and the tractive effort can never be actually zero. Most of the time, the two fields act in conjunction with one another and only at the instant when the current in either the primary or the secondary winding passes through the zero does one field act alone.

The conditions are, however, not so simple as to allow of the vibration being completely overcome by the use of short circuiting windings. It is necessary, in addition, that the magnet surfaces coming in contact with one another should be perfectly flat.

The manufacture of these cores must accord-

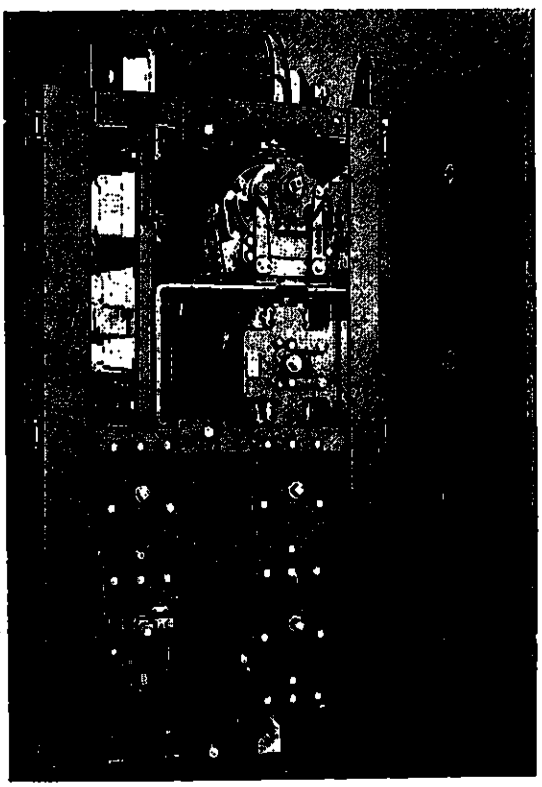


Fig. 21. Apparatus frame, detail of side.

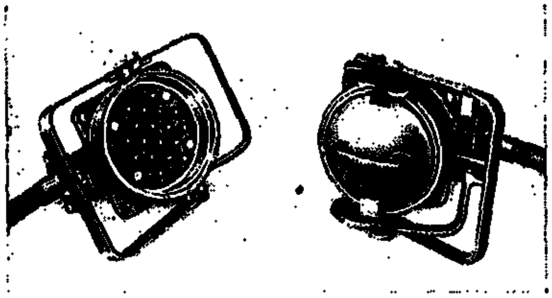


Fig. 22. Control jumper.

ingly be very carefully done. When, however, a magnet has once been made which works quietly it will continue to operate quietly. We have operated one of these contactors 2,000,000 times without being able to detect any deterioration, which means that as regards a practical amount of service it is not subject to wear. From time to time, however, it may happen that a short circuiting washer may break and then, naturally, the core must be carefully resurfaced. The short circuiting windings have their faces bevelled off to obviate the possibility of the overhanging and unsupported part being struck when the contactor closes. The air gap at the back of the magnet prevents the core from sticking.

Fig. 23. Jumper, complete with cable.

In order not to have the magnet coils too large and, at the same time, to obtain sufficient contact pressure, the contact arm and the solenoid are connected by a link gear which minimises the load on the magnet in the closed position.

The contactors for the heating current and for the ventilator and compressor motors are of much the same construction as the motor contactors. By arranging a rolling motion of the contactors on the contact arm and the greatest possible contact pressure, it is ensured that the fixed and moving contacts are kept even and in good condition while at the same time welding together of the contacts when closing is prevented. It should be specially noted that the auxiliary (interlocking) contacts move in a circular path. In this way, the necessary rubbing of the contacts and fingers against one another is obtained and good contact always ensured. This construction also allows two rows of fingers to be arranged in a simple manner, thus giving a large number of auxiliary contacts. The auxiliary contacts are protected by special pins so that it is possible to handle the contactors in any way without damaging them.

The moving auxiliary contacts on the motor contactors are placed on pivoted arms which are operated from the magnet arm. In this way, a long travel for the auxiliary contacts is obtained and, at the same time their location can be adapted so as to suit the space available. The arc shields are hung from the upper contacts and are maintained in place by flat springs. No special tools are accordingly required to remove them.

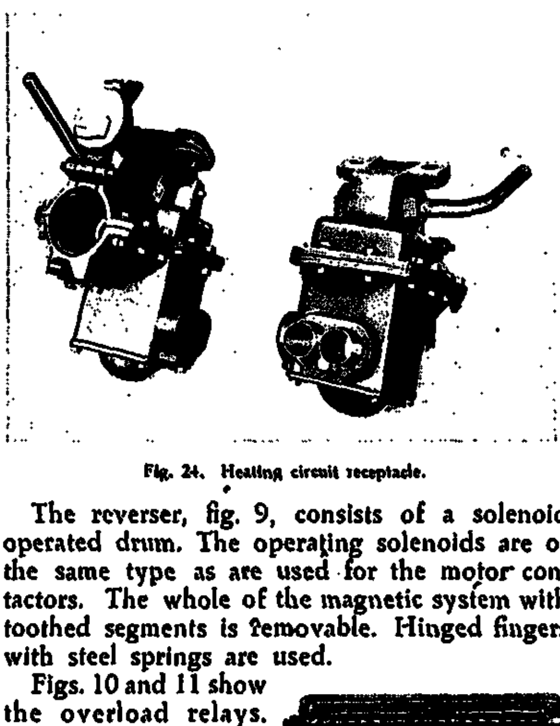


Fig. 24. Heating circuit receptacle.

The reverser, fig. 9, consists of a solenoid operated drum. The operating solenoids are of the same type as are used for the motor contactors. The whole of the magnetic system with toothed segments is removable. Hinged fingers with steel springs are used.

Figs. 10 and 11 show the overload relays. The overload relay for the motor current is adjustable within wide limits (it is calibrated for release between 2,400 and 4,000 amperes). The current transformer for this relay is contained in the main transformer tank.

The overload relay for the heating current is set for a definite release at about 700 amps. The highest current occurring in ordinary working is 450 amps.

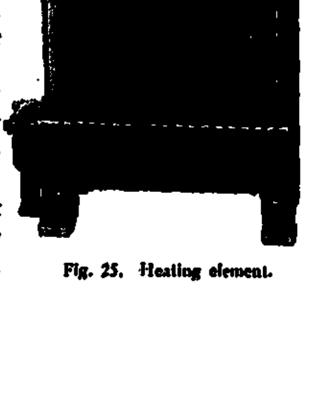


Fig. 25. Heating element.

This last overload relay is self-locking and after it has operated it must be reset by hand after the cause of operation has been removed. The current transformer for operating it is mounted on top of the apparatus frame.

The air pressure regulator and the pneumatic operating current disconnecting switch are of similar appearance as shown by fig. 12. The method of working is such that air pressure is applied to a thick membrane of rubber which in turn presses against the operating spindle for the contacts. The connecting and releasing pressures are determined by a spiral spring which presses against the rubber disc. This spring is made strong or weak corresponding to the service, *i.e.* if the apparatus is used as an air pressure governor or as an disconnecting switch.

The lighting changeover switch, fig. 14, connects the lighting of the locomotive automatically to the battery, if current in the overhead line fails.

The brake valve, with time delayed action, is shown in fig. 15. The time lag is adjustable between a fraction of 1 sec. and 30 secs. The mechanism of the time lag must not be lubricated as the viscosity of the oil used might considerably affect the time setting and the possibility would be introduced of the piston gumming up in the cylinder, particularly at low temperatures.

In fig. 16 is shown one of the three drum changeover switches for the ventilator motors, testing, and for the operating current from a rear locomotive.

Fig. 17 shows the heating switch and fig. 18 the control cutout.

Most of these pieces of apparatus are mounted in the apparatus frame shown in figs 19, 20 and 21, which illustrate respectively the front, the back and

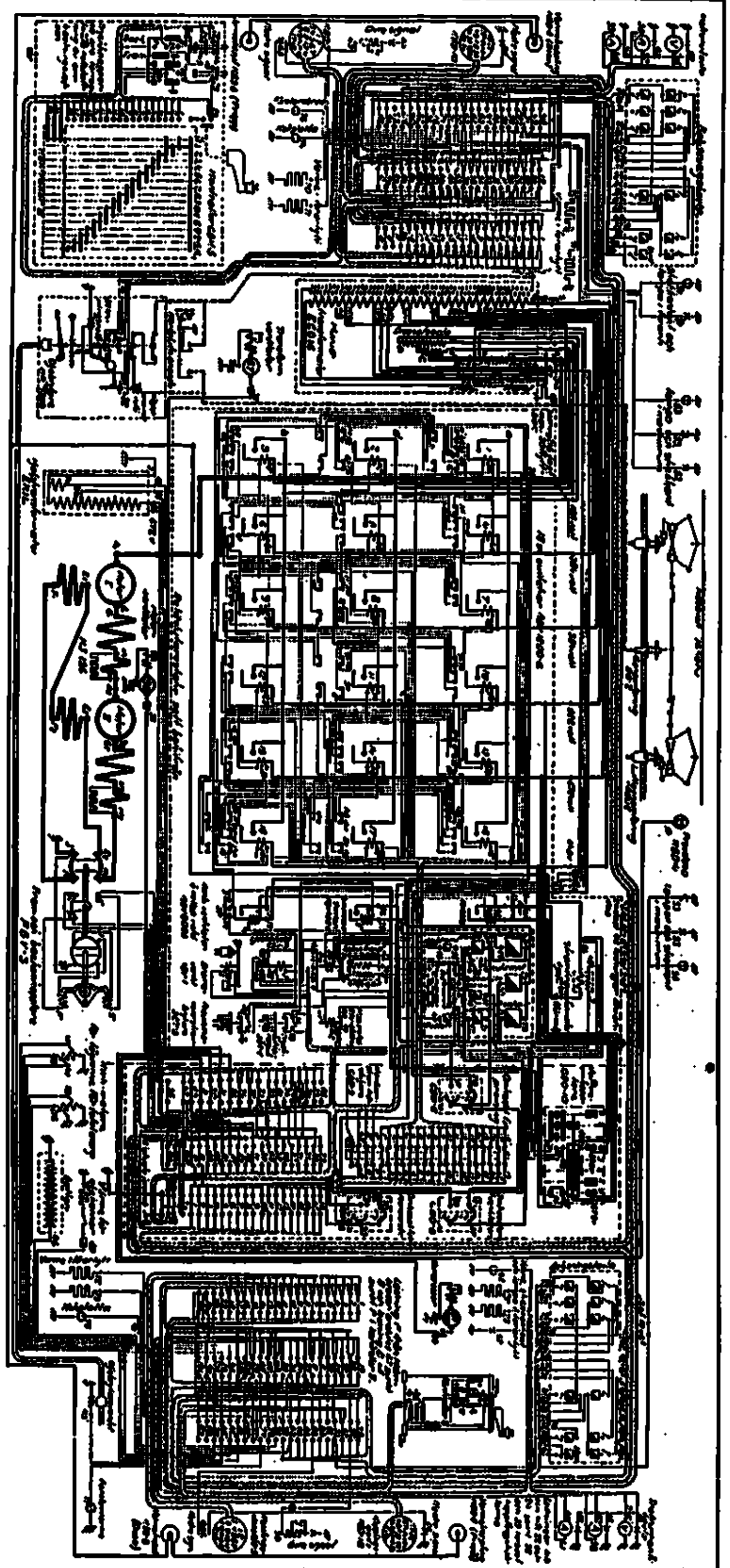


Fig. 26. Locomotive connection diagram.

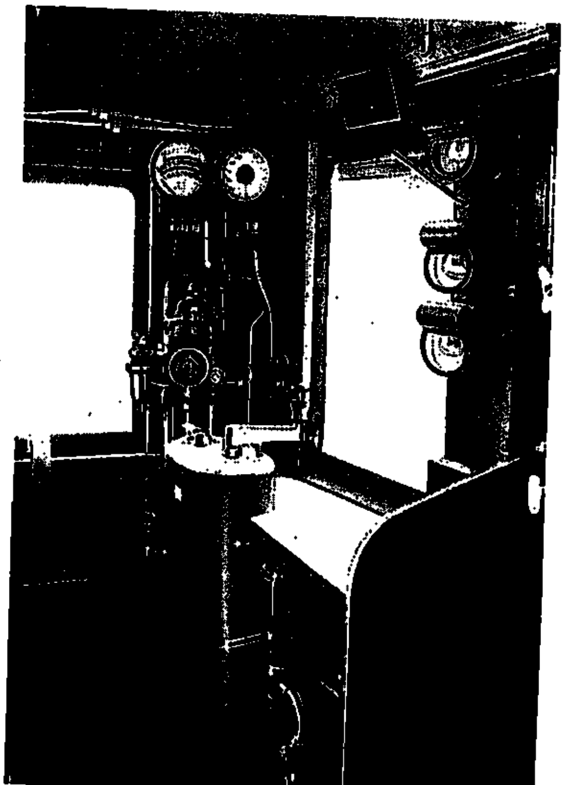


Fig. 27. Interior of driving cab.

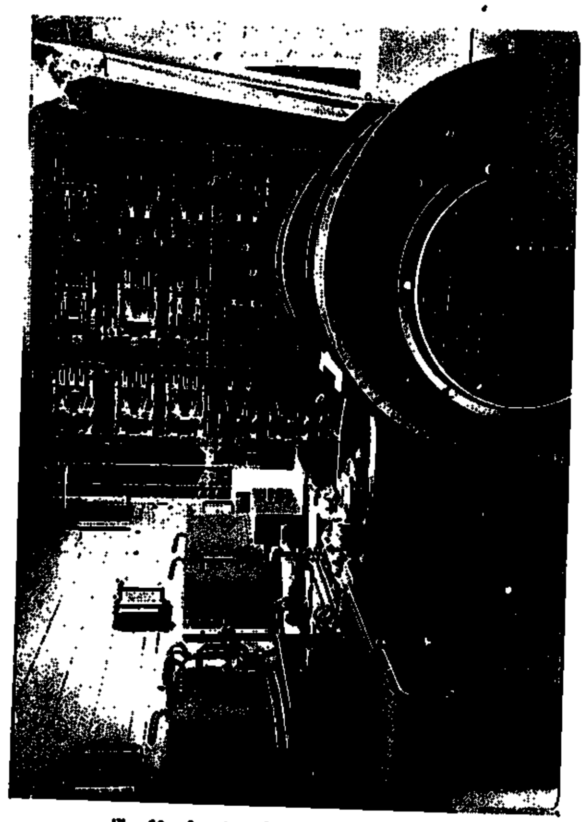


Fig. 28. Interior of machinery compartment.

one side which is protected by sheet iron doors.

All the contactors are supported upon angle irons which are insulated from the frame so that double insulation is provided between current carrying parts and the earthed frame work.

The largest amount of space in the frame is taken up by the 18 motor contactors after which (going from the top downwards) are the contactors for heating, compressors and ventilators. Nearest to the doors on the side protected by sheet iron and with their shaft ends projecting through the doors are placed all the drum changeover switches. From the top downwards these are: the heating switch, the operating current disconnecting switch, the ventilator changeover switch and the changeover switch for operating current from a rear locomotive. On the left hand side are the changeover switches for testing the operating system and below these the resetting button for the heating overload relay. At the front of the apparatus there are, in addition, the potential transformer for the heating kilowatt hour meter, the air pressure governor and the lighting changeover switch and in the rear a switchboard with fuses, overload relays for motor current and heating, the brake valve with time delayed action, and the pneumatic disconnecting switch. At the bottom of the side protected by sheet iron is placed the terminal connecting board and, when working, this is enclosed by a cover. Above the apparatus is the current transformer for the heating, and all the connecting leads and clamps which are taken direct to the transformer tappings.

Fig. 26 shows the connection diagram in a somewhat different form. The difference with respect to the diagram in fig. 1 is that all apparatus *etc.* is placed in approximately the position actually occupied on the locomotive. It also clearly shows the connections and conductors provided within the apparatus frame. The diagram would have been exceedingly complicated if all conductors had been shown, and on this account only a few conductors have been indicated, the remainder being bunched in their respective cables. All terminal points are, however, clearly denoted and all points indicated by the same figure or letter are connected with one another. With this principle in mind it is not difficult to follow out the connections, although the scale of the diagram is rather small. The markings of the terminals on the two diagrams, figs 1 and 26, are of course in full agreement.

PRECISION GEARS TYPE ASEA-STAL.

One of the most important results of the development of the steam-turbine and of marine service, together with the general endeavour in technical mechanics to use the highest possible speeds, has been the solution of the gear problem and the building of precision gears. Precision gears must, amongst others requirements, fulfil

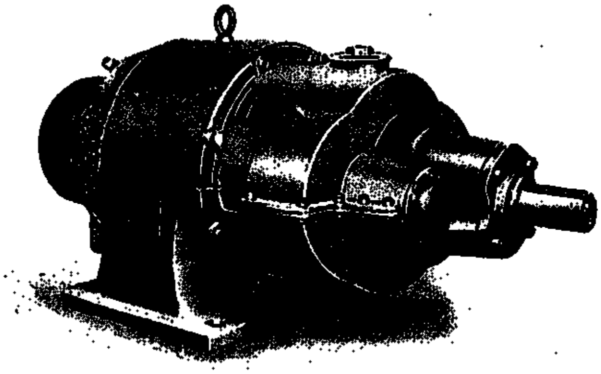


Fig. 1. Three-phase induction motor type MKA, with double gear type VD.

the following conditions: absolute safety in service, high efficiency, silent running, easy upkeep, a minimum of attendance and low maintenance costs. The results which have been obtained and the high place to which gearing has consequently been raised amongst mechanical power transmitting devices, is due partly to scientific study of the fundamentals of the theory of the gear-tooth problem and partly to greatly increased precision in manufacture.

With the steadily increased use of electricity the electric motor has assumed greater importance as a power machine. The nature of service and local and economic conditions must, in each case, be the deciding factors as to whether individual or group drive is employed with the electric motor, but, in either case, direct coupling of the motor to the driven machine or to the group shaft is to be preferred so far as simplicity and reliability of service are concerned. In many cases, however, the machines or driving shafts have so low a speed in relation to the power that direct coupled, slow-speed motors cannot be considered on account of their higher first cost, lower efficiency and, in the case of induction motors, bad power factor, when compared with high-speed motors. With A.-C. the difficulty may also arise that neither synchronous nor induction motors can be built for the speed in question. Accordingly a cheaper motor of high-speed type is, as a rule, chosen and the power transmitted by means of belt or ropes. Seldom, however, is consideration paid to the overall efficiency, or to the question of whether the interest charges are the most favourable. The need of reliable and highly efficient power transmission to low speeds has come more and more to the fore, since it is necessary to pay more careful attention to the service costs and interest charges of the plant and also because individual drive has been more extensively adopted. Gearing, which was previously used with electric motors only for certain special purposes, when it was worth while to ensure particularly reliable transmission, has, since the advent of the precision gear, completely filled the general need referred to above.

The Asea precision gears, both those for assembly with standard electric motors and those of the self-contained type, are designed and manufactured in accordance with the principles and methods worked out and applied for many years by Stal, our double rotation turbine works which are known all over the world as first class precision works, and which have put in the manufacture of their gears, the precision methods which were indispensable for the manufacturing of their turbines. These gears, which are of solid construction throughout, provide a rational solution of the gear problem and fulfil in the highest degree all the requirements of precision gearing. So far as the transmission element is concerned they can most nearly be compared to transformers in respect

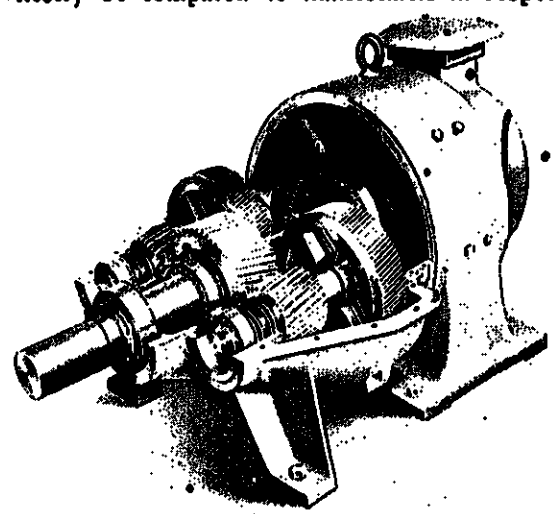


Fig. 2. D.C. motor type K, with double gear type VD. (Upper half of gear casing removed).

of efficiency. With the larger gears and moderate peripheral speeds the losses are hardly measurable while the efficiency of smaller gears falls, in certain instances, to a minimum value of about

97.5 %. These good efficiencies are almost entirely due to perfect tooth-form and extremely careful cutting of the teeth. While the teeth are

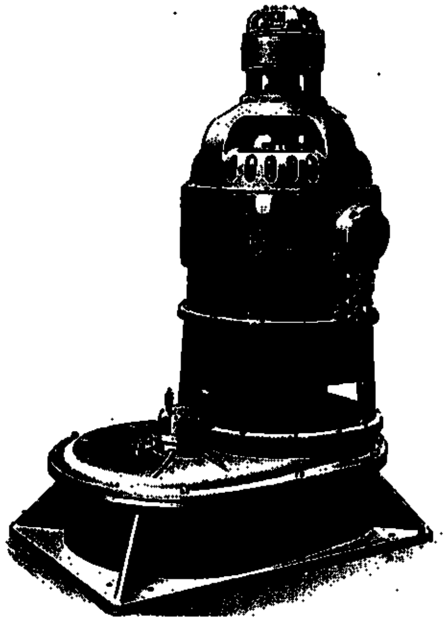


Fig. 3. Vertical three-phase generator type GSA, with single gear type VES, 300 kVA at 150 r.p.m., for direct connection to water turbine.

engaged, except during the practically frictionless rolling period, there is always a certain amount of sliding and consequent friction. The coefficient of friction for sliding should therefore be kept to its lowest possible value. In the Asea-Stal gears this is arrived at by means of efficient lubrication of the teeth, generally ensured by allowing the larger wheel to dip into an oil bath and distribute the oil to all other parts of the gear. In addition the gears are provided with ball bearings, except in certain cases with the self-contained gears. The wear is also particularly small, owing to the efficient lubrication, and this, in combination with the very small number of parts exposed to wear, results in low maintenance costs and great reliability in service, conditions which can be substantiated by gears which have been in service for over ten years.

Motors combined with precision gears are consequently, from an electrical point of view, superior to slow speed motors for the same outputs and mechanically they are equivalent. When compared with belt or rope transmission, which as a rule has a very low efficiency (varying between about 95 and 60 %), their good qualities appear even more marked. In view of the great advantages which geared motors offer for any desired low speed or with a wide range of low speeds — even with three-phase current, through the use of variable speed three-phase commutator motors — when selecting a drive, consideration should be paid to the question of whether such a motor would not be the most favourable both with regard to first cost, service costs, and interest charges.

When direct coupling of the comparatively cheaper high-speed motors is not possible, precision gears can advantageously be used, in most cases, to replace the transmission devices which have up till now been used and this substitution, as pointed out in the introduction, is a profitable one. This depends not only on their great reliability in service, their outstandingly high efficiency and their low maintenance costs but also on their simple upkeep, their small need of attendance and the small space they occupy, thereby allowing the number of attendants to be cut down, valuable space set free and building costs reduced. In addition they offer the advantages of silent running, simple erection and adaptability to different conditions when erecting. The power distribution in industrial plants has been greatly simplified by the use of motors in conjunction with precision gears and power transmission has, in certain cases, been made possible in an excellent and cheap manner.

As examples of machinery with which it has been found advantageous to use precision gears, may be cited:

in the steel and mining industries: ore-dressing machines, crushers, slime-pumps, sinter-fans, rolling mills, draw-benches, rolling tables, feed tables, hoists and transporters;

in foundries: edge-runner mills, black and loam mixers, tumbling wheels, drying ovens, *etc.:*

in the metal and wood-working industries: lathes, planes, drills, milling machines, and in short, all machine tools;

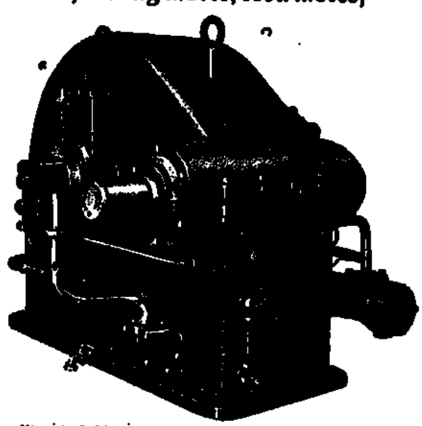


Fig. 4. Self-contained single gear type M2V, with sleeve bearings, oil pump and oil cooler.

in the wood pulp, cellulose and paper industries: pulpers, sorting tables, pugmills, refiners, pulp pumps, hollanders, jordan beaters, paper machines, calenders, reeling machines, *etc.:*

in the textile industries: openers, scutchers, carding machines, sizers, spinning frames, soap boilers, washing machines, starching machines, mangles, printing machines, hot flues, calenders, *etc.:*

in cement mills: crushers, cement and ball mills, rotary kilns, *etc.:*

in the flour milling industry: for mills, *etc.:*

in other industries: printing-presses, fans, centrifugal pumps, separators, lifts, hoists, haulage gears, transmission in general, ship propulsion, *etc.* and in certain cases for compressors and plunger-pumps.

In the case of electric generators, as for electric motors, the size, price and weight at constant output increase with decrease in speed. The use of high-speed, cheap and light generators combined with precision gears direct connected to water turbines has, however, facilitated the economic utilisation of small water falls with low head. Similarly the precision gear in certain cases — with smaller sets up to about 1000 kW and sometimes at higher outputs — offers technical and economic advantages as a link between a steam turbine and a generator.

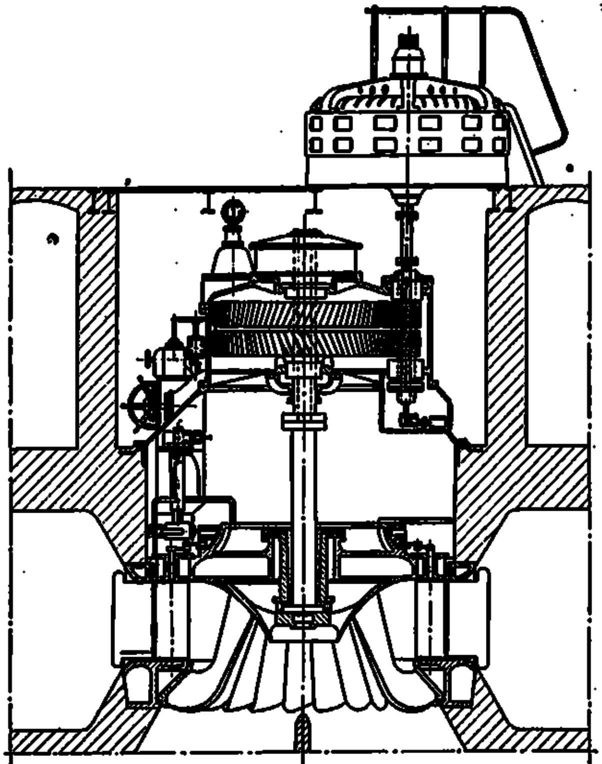


Fig. 5. Sketch of arrangement of generator driven by water turbine through precision gear for gearing up the speed.

In order to show the approximate extent of the saving which the use of gearing allows, the following examples may be given:

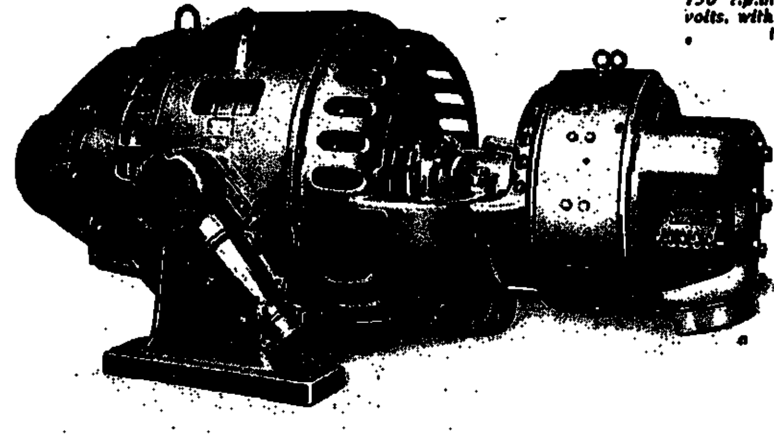
An induction motor of from 200 to 300 h.p. at 150 r.p.m. is approximately 33 % more expensive than a high speed motor and gear for the same output. The power factor is also improved about 25 % and the overall efficiency is somewhat higher when using gearing.

An autosynchronous motor of 200 kVA at 200 r.p.m. is, with exciter, about 25 % more expensive than a geared motor of the same output.

A vertical synchronous generator of 150 to 300 kVA at 83 r.p.m. is about 33 % dearer than a generator and gear for the same output. The efficiency with gearing is improved approximately 2 %.

The above short survey, will serve to give an idea of the very great range of application of precision gears in combination with electric machines and also the important advantages, which can be gained by their use, in respect both of the technique of the service and of capital charges of the plant.

Three-phase autosynchronous motor type MAG, 230 kVA, 750 r.p.m., 50 cycles, 380 volts, with exciter and reduction gear.



AUTOSYNCHRONOUS MOTORS

Autosynchronous motors are superior to other alternating current motors running at constant speed, as they combine in one machine the good starting characteristics of the induction motor and the power factor correcting possibilities of the synchronous motor. They can also be started against full load torque like induction motors and when normal speed has been reached the changeover switch enables them to be excited, after which they run like synchronous motors. No separate starting motor or synchronising arrangement is required.

The autosynchronous motor, unlike the induction motor, has the advantage that it does not give rise to lagging power factor in a supply to which it is connected. Like the synchronous motor it can be over-excited for any power factor required, right up to zero leading, for improving the power factor in a network.

The autosynchronous motor as opposed to the synchronous motor has the advantage that it will not pull up if an overload occurs or the voltage falls, but continues to run as an induction motor until the load is reduced or the voltage rises to the normal, after which it again runs in synchronism.

The autosynchronous motor is exceedingly useful where difficult starting conditions are to be expected although synchronous characteristics are required and it is particularly suitable for driving centrifugal pumps, fans, calenders, compressors, grinders *etc.*

The autosynchronous motor was patented by Asea in 1900 and such motors have since been built in all sizes up to 2,000 kVA and for power factors from 0.9—0 with over-excitation.

ASEA

VESTERAS — SWEDEN

Vesteras 1927, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

ALLMÄNNA SVENSKA ELEKTRISKA A.B.
VESTERÅS — SWEDEN

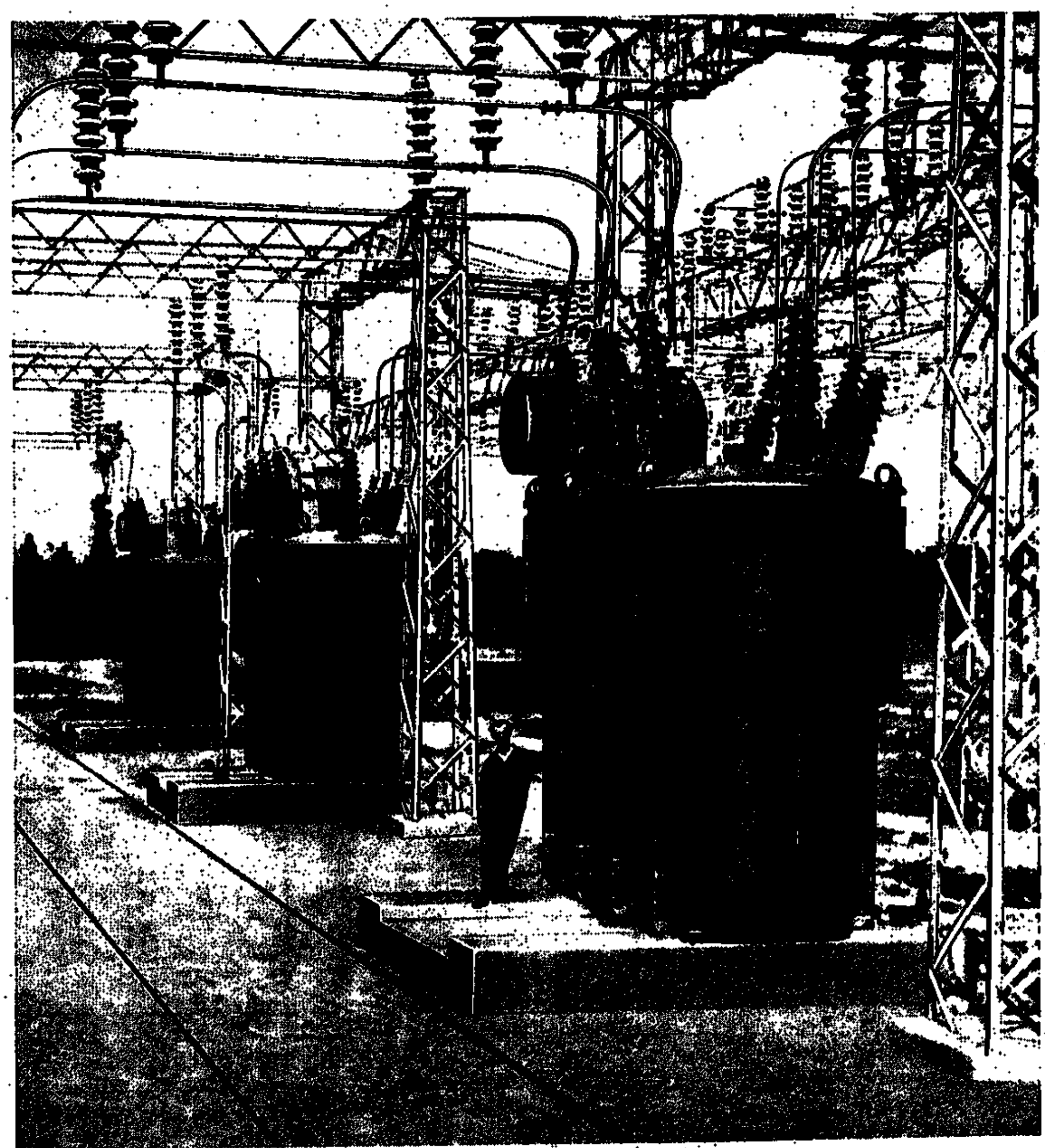
SWEDISH GENERAL ELECTRIC LTD
5. CHANCERY LANE—LONDON

MONTHLY REVIEW

VOL. IV 1927

All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesterås, Sweden.
Permission is given to reprint articles or extracts from this journal, on condition that the name — Asea-Journal — is clearly stated.

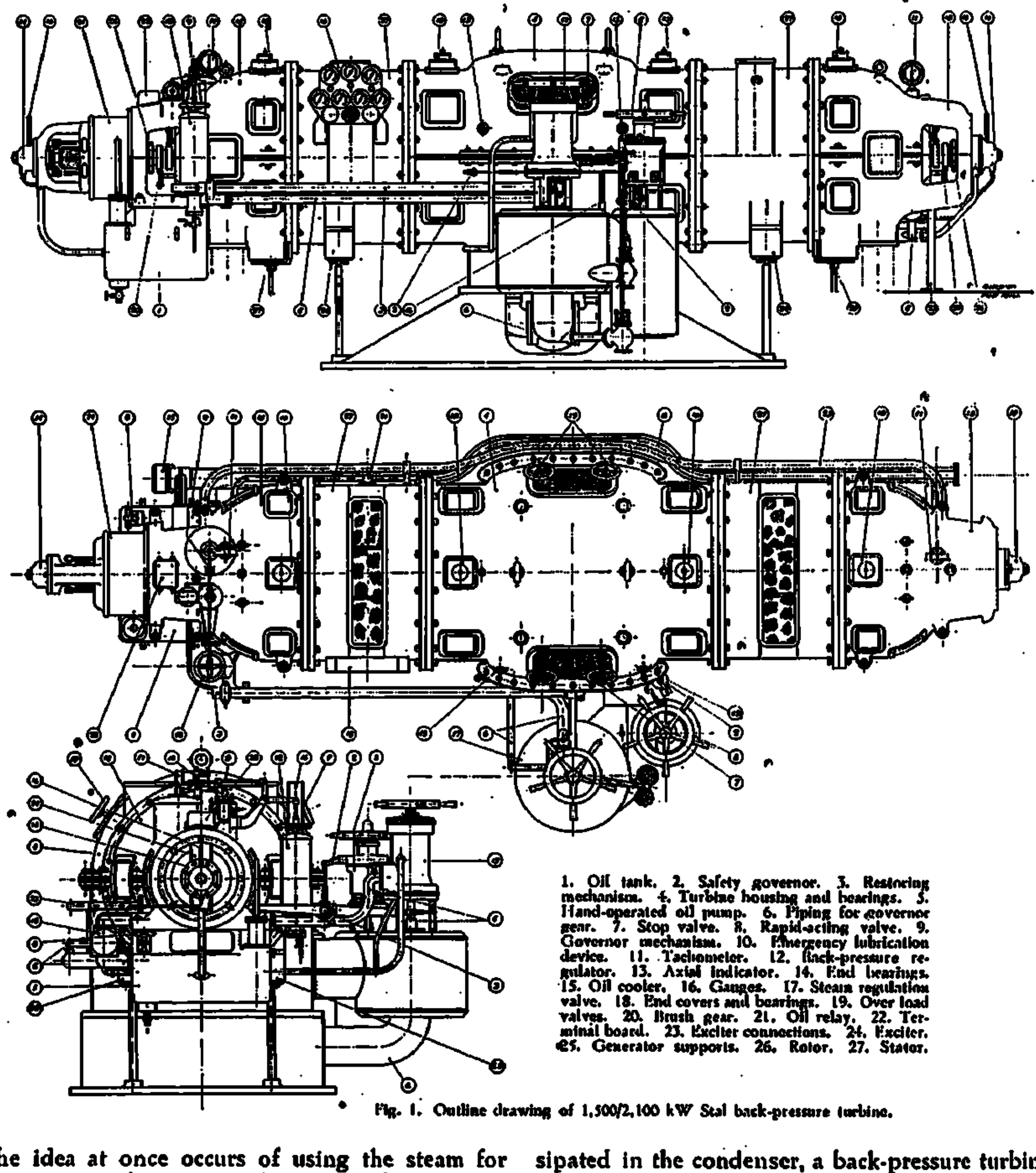
AUGUST No 8



Soc. Generale Elettrica dell'Adamello, Italy. The transformer station at San Polo d'Enza.
3 Asea three-phase transformers, each for 10,000 kVA $117/\frac{70}{67}$ kV, 42 cycles.

NEW STAL DOUBLE-ROTATION, BACK-PRESSURE TURBINE, TYPE DM.,

In industrial plants, where steam in large quantities is required for various heating purposes such as warming, boiling, drying, *etc.* the idea at once occurs of using the steam for generation of power, making use of the expansion between boiler pressure and the pressure at which the heating steam is required. The energy which is thus obtained from the steam is produced at an efficiency of nearly 100 %, if radiation and electrical losses be disregarded. Compared with a condensing turbine, where the greater part of the heat in the steam must be dissipated in the condenser, a back-pressure turbine accordingly uses only about $^1/_6$ of the fuel, for the same output. The consumption of coal per kilowatt year, assuming that the power is used for 7,000 hours, is only from 1 to 1.5 tons, and it is accordingly understandable that back-



1. Oil tank. 2. Safety governor. 3. Restoring mechanism. 4. Turbine housing and bearings. 5. Hand-operated oil pump. 6. Piping for governor gear. 7. Stop valve. 8. Rapid-acting valve. 9. Governor mechanism. 10. Emergency lubrication device. 11. Tachometer. 12. Back-pressure regulator. 13. Axial indicator. 14. End bearings. 15. Oil cooler. 16. Gauges. 17. Steam regulation valve. 18. End covers and bearings. 19. Over load valves. 20. Brush gear. 21. Oil relay. 22. Terminal board. 23. Exciter connections. 24. Exciter. 25. Generator supports. 26. Rotor. 27. Stator.

Fig. 1. Outline drawing of 1,500/2,100 kW Stal back-pressure turbine.

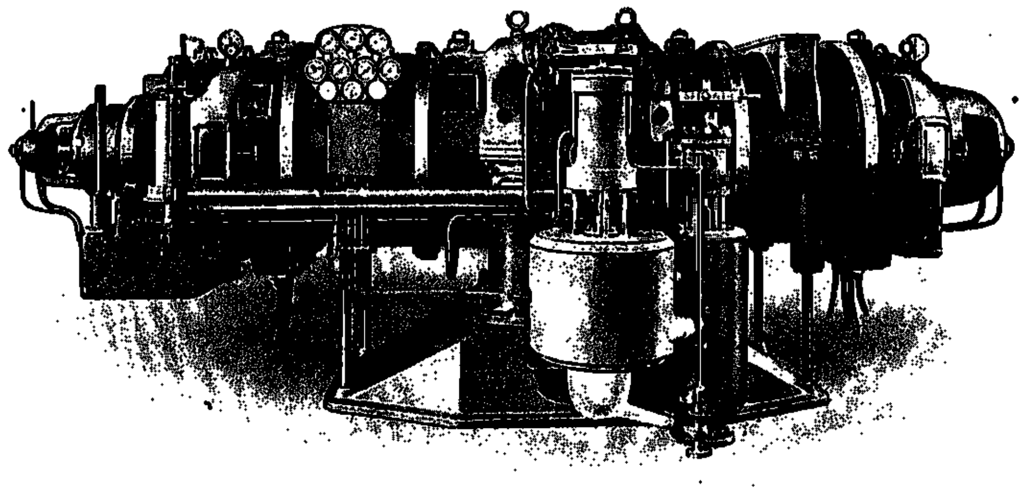


Fig. 2. 2,100 kW Stal back-pressure turbine.

pressure turbines are being much more widely used, even in places where water power is available at a relatively moderate price. On the assumption that the pressure for the heating steam cannot be reduced, there are two possibilities of increasing the amount of cheap back-pressure power available. One of these is to increase the steam pressure and temperature in the boilers, the other to raise the thermo-dynamic efficiency of the turbine. If in any case new boilers have to be provided, it is accordingly an advantage to design them for a higher steam pressure, particularly as the increase in the cost of the plant for pressures up to 300 to 360 lbs per sq. in. is not too great. Whether it will pay to scrap existing boilers which are in good condition, and install boilers for a higher pressure, must be investigated in each special case. On the other hand, it is always of assistance in procuring cheap back-pressure power, that the steam turbine work with the highest possible thermo-dynamic efficiency. In this respect also great strides have been made during the last few years by steam turbine builders.

The Stal Company has now put on the market a back-pressure turbine, type DM, which, as regards efficiency and simplicity of construction, embodies qualities which have everywhere awakened the greatest interest. It runs with particularly high thermo-dynamic efficiency and accordingly gives the greatest power output for a given quantity of steam. The accompanying illustrations (figs. 1, 2 and 3) give a general

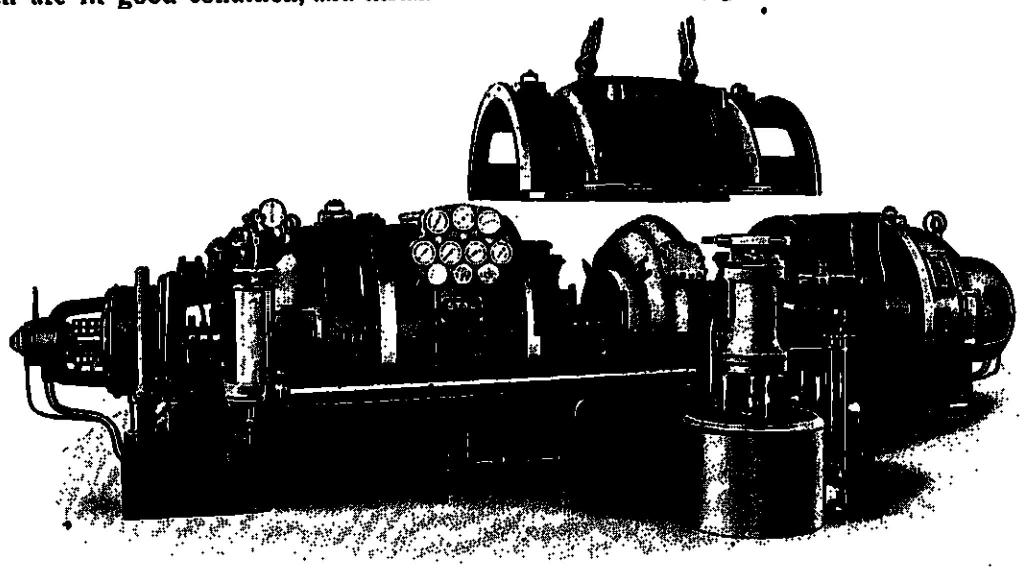


Fig. 3. 2,100 kW Stal back-pressure turbine with upper half of turbine housing raised. The illustration shows the inner insulated turbine housing.

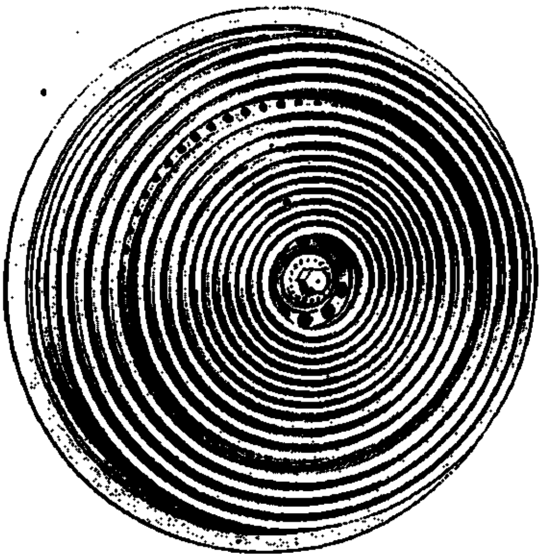


Fig. 4. One half of blade system for Stal back-pressure turbine.

impression of the appearance of the set. It is, with a few alterations, an ordinary double-rotation Stal turbo-generator, which is, as is well known, of the radial type, *i.e.* the steam enters in the centre of the blade system, afterwards flowing out radially, the blades being axially placed. The two turbine wheels rotate in opposite directions, so that the blades on one wheel act as guide blades for the other wheel. Each of the turbine wheels is connected with one of the two rotors of the turbo-generators. These also rotate in opposite directions and are electrically synchronised, so that they run at precisely the same speed.

The departures from Stal's standard condensing turbine are as follows. As there is no vacuum in the case of a back-pressure turbine, the condenser and accompanying equipment are eliminated. The turbine housing, which still supports the two generators, is placed on a bedplate (see fig. 1), which for the larger types — as in the case of the standard condensing types — is provided with stays for supporting the stators. The blade system (fig. 4) being specially designed for back-pressure work, accordingly contains a smaller number of rings than for the condensing turbines, and the outer ring has a smaller diameter. Inside the ordinary turbine housing is placed a special inner housing of steel (see figs. 3 and 5). This is required on account of the high pressure of the steam (15 to 150 lbs/sq. in.) which is obtained from the last stage. It is, in addition, well heat insulated to prevent loss of heat between the steam and the surroundings. Lastly, the inlet valve is considerably larger than for a condensing turbine, due to the large quantity of steam which a back-pressure turbine has to pass.

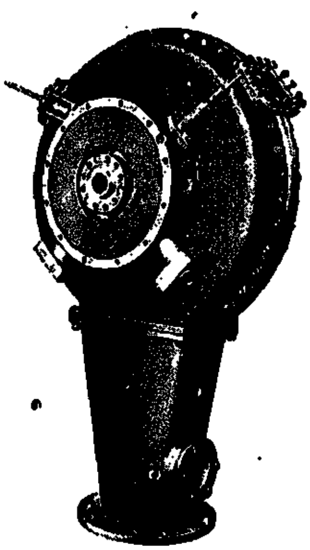


Fig. 5. Inner turbine housing for Stal back-pressure turbine.

High-pressure steam is led to the turbine in the usual manner, through holes in the boss of the turbine wheels to the inner ring of blades (fig. 4) and the back pressure steam is taken downwards from the bottom of the housing.

The governing arrangements are somewhat different from those used with condensing turbines of ordinary design. Back-pressure turbines are provided in most cases, not only with speed regulating governors, but also with back-pressure regulators of a design developed by Stal, which under given conditions act so as to give a constant back pressure. Usually, a back-pressure turbine works in parallel with other generating plant and in this case the regulator functions so as to give constant back pressure, under all conditions. Since it is not poss-

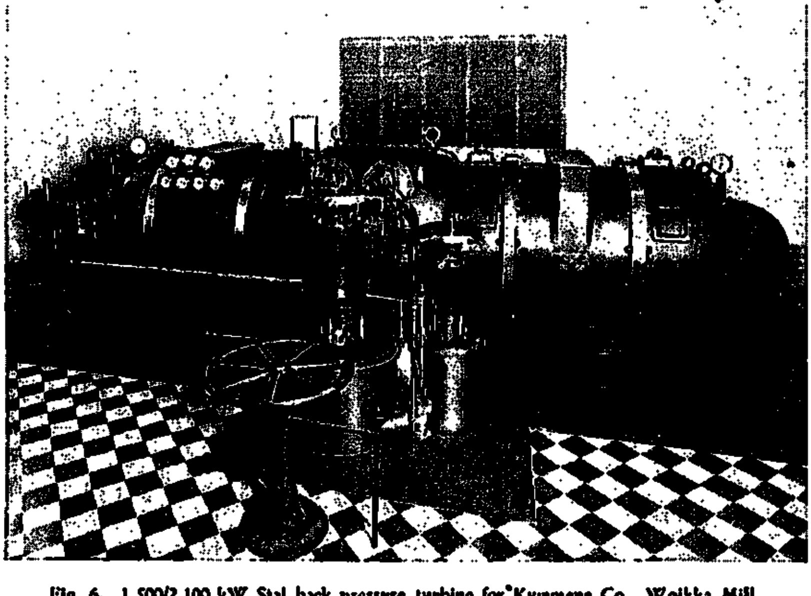


Fig. 6. 1,500/2.100 kW Stal back pressure turbine for Kymmene Co., Woikka Mill, Kuusankoski, Finland.

ible to govern for constant speed and also, at the same time, to regulate for constant back pressure, the governing actuated by the speed is in such cases put out of action. When a back pressure turbine runs alone, the speed is governed and the back pressure regulator thrown out, so that the back pressure is dependent on the generator load and on the demand for back-pressure steam.

So far, 16 turbines of the new back pressure type have been supplied for a total output of 21,000 kW. At the tests carried out on machines already delivered, thermodynamic efficiencies have far exceeded anything previously obtained. We give below some extracts from two official test reports, where the efficiency, in spite of relatively unsatisfactory conditions, exceeds 85 %. Figs. 6 and 7 show these two turbines as installed in the power stations.

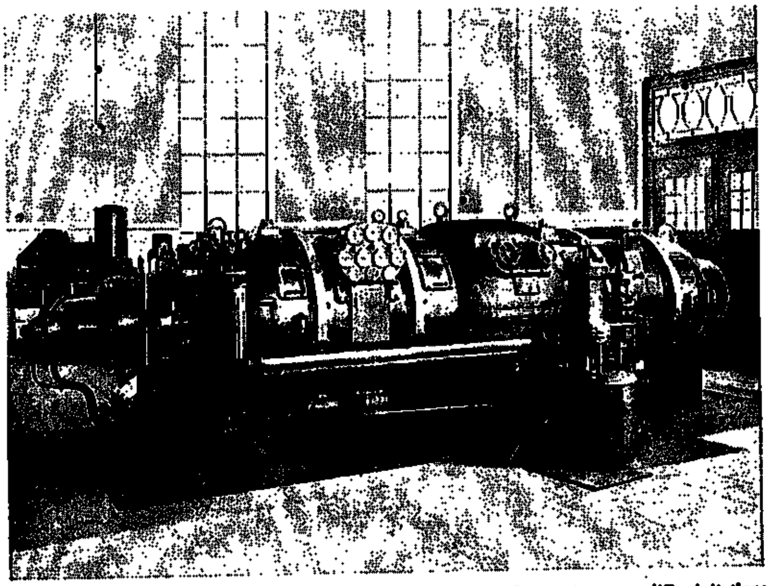


Fig. 7. 1,500/2,100 kW Stal back pressure turbine delivered to Société Anonyme d'Exploitations Minières, Pechelbronn, Alsace-Lorraine

Official test

on 1,500/2,100 kW back-pressure turbine for the Woikka Paper Mills, Kuusankoski, Finland, carried out by "The Society for Power and Fuel Economy", Helsingfors, Finland.

Guarantee Conditions:

Admission pressure (gauge) ... 242 lbs./sq. in.
Back pressure (gauge)............ 42.7 " "
Admission temperature............ 300° C.
Maximum quantity of steam ... 30 tons/hour.
Speed.................................. 3,000 r.p.m.

Test results:

Normal output of Turbine, kW	1500			
Steam pressure on leaving inlet valve, lbs./sq. in. abs.	170.8	202.1	243	256.1
Back pressure, lbs./sq. in. abs.	59.9	54.6	57	57
Steam temperature on leaving inlet valve, °C	267.4	273.3	289.3	294.6
Output, kW	774.0	1047.1	1440.9	1815.9
Total quantity of steam, lbs./hour..................	33058	38094	45699	57358
Thermo-dynamic efficiency (referred to conditions after regulating valve and shaft output), % ...	83.2	85.0	85.2	82.3*)

Official test

on 1,500/2,000 kW back-pressure turbine for the Société Anonyme d'Exploitations Minières, Pechelbronn, Alsace-Lorraine, carried out by "Association Alsacienne des Propriétaires d'Appareils à Vapeur", Strassburg.

Guarantee Conditions:

Admission pressure (gauge) ... 256 lbs./sq. in.
Back pressure (gauge)............ 42.7 " "
Admission temperature .... 320° C.
Maximum quantity of steam ... 25 tons/hour.
Speed .... 3,000 r.p.m.

Test results:

Normal output of Turbine, kW	1500		
Steam pressure at inlet valve, lbs./sq. in. (gauge)	258.8	263.[illegible]	263.1
Back pressure, lbs./sq. in.	45.5	48.35	45.5
Steam temperature at inlet valve, °C	308	301	292
Output, kW	1605	1136	873
Thermo-dynamic efficiency (referred to conditions after regulating valve and shaft output), %	84.2	85.1	83.1
Measured steam consumption, lbs./hour	47959	38521	33185
Guaranteed steam consumption, lbs./hour.........................	50494	40241	33736
Improvement on guaranteed steam consumption, %	5.0	4.3	1.6

As the above extracts from Test Reports show, the guarantees have been exceedingly well maintained. In both the cases cited, Stal also obtained a premium for the improvement in steam consumption per kWh generated. It will be seen that the thermo-dynamic efficiency exceeds 85 %. For turbines working under more favourable conditions than is the case here, the efficiency should be further improved, in which case Stal back-pressure turbines will become almost indispensable for the service we have touched upon here.

*) On overload.

"VARIABLE SERIES POWER FACTOR CORRECTION" WHEN POLYPHASE INDUCTION MOTORS ARE CONNECTED IN CASCADE WITH POLYPHASE SHUNT COMMUTATOR MOTORS.

This paper deals with a special problem of regulation which arises when polyphase induction motors are connected in cascade with polyphase shunt commutator motors. It is known that speed regulation, compounding, or power factor correction of polyphase induction motors, if effected without losses, demands the application of a voltage E_2 of suitable magnitude and phase to the secondary circuit. It can easily be shown that this voltage for a given speed should not be constant but must have a component which is proportional to the primary or secondary main current. Such a voltage is referred to as a "series voltage". It should further be noted that this series voltage must in turn not be the same for all speeds but must contain a component which takes account of the difference between no load speed and the synchronous speed. If this component is omitted very poor power factor correction is obtained as soon as the no load speed departs to any great extent from the synchronous speed. Bearing this in mind we shall designate this series voltage as a "variable series power factor correcting voltage". The expression is rather long but has the advantage of expressing exactly what is intended. In the following, the magnitude and phase of this component will first be calculated by an exceedingly simple method. After this we describe several connections which can be used in the practical application of the theory.

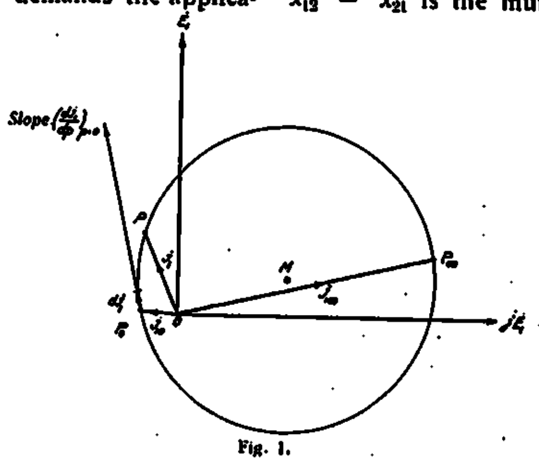


Fig. 1.

I. *Theoretical investigations.*

As an analytical expression for the primary and secondary voltage diagram for an induction motor we can make use of the following familiar equations:

$$\dot{E}_1 = \dot{I}_1 (r_1 - jx_1) - j\dot{I}_2 x_{21} \;\ldots\ldots\ldots\ldots\; 1)$$

$$\dot{E}_2 = \dot{I}_2 (r_2 - jx_2 s) - j\dot{I}_1 x_{12} s \;\ldots\ldots\ldots\ldots\; 2)$$

In the above:

$\dot{E}_1$ and $\dot{E}_2$ are time vectors for the primary and secondary terminal voltage (per phase).

$\dot{I}_1$ and $\dot{I}_2$ are time vectors for the primary and secondary current.

r_1 and r_2 are the ohmic resistances of the windings.

x_1 and x_2 are the total reactances of the winding including leakage (calculated, as for all reactances denoted by x, for the periodicity of the supply).

$x_{12} = x_{21}$ is the mutual reactance between the stator and rotor, which determines the coefficient $\sigma = 1 - \frac{x_{12} x_{21}}{x_1 x_2}$ for the total leakage.

s_0 and s are the rotor slips below the synchronous speed at no load and on load respectively.

The secondary voltage E_2 is generated by cascade connection with a three-phase commutator machine and, in general, is either practically independent of the slip, or proportional to the speed of the main motor, *i.e.* proportional to $1-s$. Accordingly if we assume E_2 proportional to $1 - \frac{s}{s_k}$ where s_k is either infinity or equal to 1, we can investigate both cases together. Taking this into account we can put

$$\dot{E}_2 = (\dot{E}_1 \dot{x} + \dot{I}_1 \dot{y}_{12} - \dot{I}_2 \dot{y}_2)\left(1 - \frac{s}{s_k}\right) \ldots\ldots\; 3)$$

The first component $\dot{E}_1 \dot{x}\left(1 - \frac{s}{s_k}\right)$ determines only the slip s_0 at no load and the no load currents I_{10} and I_{20}. The power factor correction on load and the speed characteristic (the compounding) is determined by the two series voltages which form the second and third terms in equation 3. x, y_{12} and y_2 are, in general, complex quantities.

The calculation can be simplified by the introduction of a new parameter

$$p = \frac{s}{1 - \frac{s}{s_k}} - \frac{s_0}{1 - \frac{s_0}{s_k}} \;\ldots\ldots\ldots\ldots\ldots\; 4)$$

which has the characteristic of always being zero for no load and infinity for $s = s_k$. Accordingly, if we put

$$p_0 = \frac{s_0}{1 - \frac{s_0}{s_k}} \;\ldots\ldots\ldots\ldots\ldots\ldots\; 4a)$$

we obtain the voltage equations for the primary and secondary circuits (1 and 2) in the following form:

$$\dot{E}_1 = \dot{I}_1(r_1 - jx_1) - j\dot{I}_2 x_{21} \quad \ldots\ldots\ldots\ldots 1)$$

$$\dot{E}_1 \dot{\varkappa} = -\dot{I}_1[\dot{y}_{12} + jx_{12}(p+p_0)] +$$
$$+ \dot{I}_2\left[r_2 + \dot{y}_2 + \left(\frac{r_2}{s_k} - jx_2\right)(p + p_0)\right] \quad \ldots\ldots 5)$$

We can assume that the no load currents $\dot{I}_{10}$ and $\dot{I}_{20}$ are the same for all values of speed, which can easily be reached by a suitable choice of $\dot{\varkappa}$. But in addition to this we also require the phase displacement of the primary current to be independent of the no load speed even on load. This requirement is met if the differential $\frac{d\dot{I}_1}{dp}$ for $p = 0$ (*i.e.* for no load) is independent of p_0 (*i.e.* of the speed.) For the differential

$$\left(\frac{d\dot{I}_1}{dp}\right)_{p=0}$$

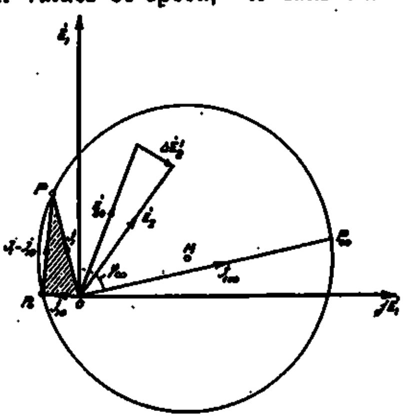


Fig. 2a.

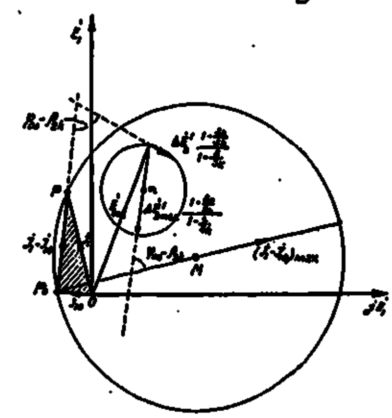


Fig. 2b.

determines the tangent at the no load point in the primary current diagram*) (compare fig. 1). We accordingly differentiate equations 1 and 5 for $p = 0$ and obtain:

From equation 1

$$0 = \left(\frac{d\dot{I}_1}{dp}\right)_{p=0} \cdot [r_1 - jx_1] - j\left(\frac{d\dot{I}_2}{dp}\right)_{p=0} x_{21}$$

and from equation 2

$$j\dot{I}_{10}x_{12} - \dot{I}_{20}\left(\frac{r_2}{s_k} - jx_2\right) = -\left(\frac{d\dot{I}_1}{dp}\right)_{p=0} \cdot [\dot{y}_{12} + jx_{12}p_0] +$$
$$+ \left(\frac{d\dot{I}_2}{dp}\right)_{p=0} \cdot \left[r_2 + \dot{y}_2 + \left(\frac{r_2}{s_k} - jx_2\right)p_0\right]$$

From this we obtain the following solution in the determinant form:

$$\left(\frac{d\dot{I}_1}{dp}\right)_{p=0} = \frac{\begin{vmatrix} 0 & -jx_{21} \\ j\dot{I}_{10}x_{12} - \dot{I}_{20}\left(\frac{r_2}{s_k} - jx_2\right) & r_2 + \dot{y}_2 + \left(\frac{r_2}{s_k} - jx_2\right)p_0 \end{vmatrix}}{\begin{vmatrix} r_1 - jx_1 & -jx_{21} \\ -\dot{y}_{12} - jx_{12}p_0 & r_2 + \dot{y}_2 + \left(\frac{r_2}{s_k} - jx_2\right)p_0 \end{vmatrix}} \quad 6)$$

The numerator is independent of the speed (p_0). Accordingly if the whole expression is to be independent of p_0, then $\dot{y}_{12}$ and $\dot{y}_2$ must be so determined that p_0 disappears in the denominator also. This is only possible if $\dot{y}_{12}$ and $\dot{y}_2$ each contain a component $\dot{y}'_{12}$ and $\dot{y}'_2$ respectively which is proportional to p_0 and if, in addition, the equation

$$(r_1 - jx_1)\left[\dot{y}'_2 + \left(\frac{r_2}{s_k} - jx_2\right)p_0\right] - jx_{21}\left[\dot{y}'_{12} + jx_{12}p_0\right] = 0 \quad 7)$$

is satisfied. We thus have to investigate the law which this agreement requires for the variable series power factor correcting voltage.

We obtain first of all from equation 7;

$$\dot{y}'_2 \cdot \frac{r_1 - jx_1}{\frac{r_2}{s_k} - jx_2} + \dot{y}'_{12}\frac{-jx_{21}}{\frac{r_2}{s_k} - jx_2} =$$
$$= -p_0\left[(r_1 - jx_1) + \frac{x_{12}x_{21}}{\frac{r_2}{s_k} - jx_2}\right] \quad \ldots\ldots\ldots 8)$$

Now the expression by which p_0 is multiplied is equal to the resulting impedance of the induction motor for $p = \infty$ ($s = s_k$). We denote this impedance by

$$\left.\begin{aligned} \dot{z}_\infty &= r_\infty - jx_\infty \\ &\text{and develop for } s_k = \infty \\ \dot{z}_\infty &= r_1 - jx_1\sigma \\ &\text{and for } s_k = 1 \text{ respectively} \\ \dot{z}_\infty &= r_1 + r_2\frac{x_1}{x_2}\frac{1-\sigma}{1+\frac{r_2^2}{x_2^2}} - jx_1\frac{\sigma + \frac{r_2^2}{x_2^2}}{1+\frac{r_2^2}{x_2^2}} \\ &\doteq r_1 + r_2\frac{x_1}{x_2}(1-\sigma) - jx_1\sigma \end{aligned}\right\} 9)$$

*) Strictly speaking $\left(\frac{di_1}{dp}\right)_{p=0}$ certainly also determines the compounding so that we need not go further into the matter in this connection.

We then obtain equation 8 in the final form:

$$\dot{y}'_{12}\frac{x_{21}}{x_2+j\frac{r_2}{s_k}}+\dot{y}'_2\frac{x_1+jr_1}{x_2+j\frac{r_2}{s_k}}=-p_0\dot{z}_\infty \quad \ldots\ 10)$$

Examination of the formula expressed by equation 10 enables us to obtain one important

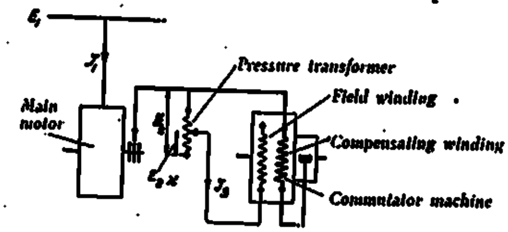


Fig. 3.

conclusion immediately. It is clear that the variable series phase compensation can be obtained equally well either by the help of the primary current through $\dot{I}_1\dot{y}'_{12}$ or by the help of the secondary current through $-\dot{I}_2\dot{y}'_2$. We are accordingly always free to choose the most simple connection which in general leads to the special assumption of $y'_2=0$.

We accordingly investigate the magnitude and phase displacement of the auxiliary voltage

$$\dot{E}'_2=(\dot{I}_1\dot{y}'_{12}-\dot{I}_2\dot{y}'_2)\left(1-\frac{s}{s_k}\right) \ldots\ldots\ldots\ 11)$$

which in accordance with equations 3 and 10 gives the same phase compensation at all speeds, and we obtain

$$\dot{E}'_2=-\dot{I}_1\dot{z}_\infty s_0\cdot\frac{x_2+j\frac{r_2}{s_k}}{x_{21}}\cdot\frac{1-\frac{s}{s_k}}{1-\frac{s_0}{s_k}} \ldots\ldots\ 12)$$

or disregarding the phase displacement this is nearly enough

$$E'_2\cdot\left(\frac{N_1}{N_2}\right)=I_1x_1\sigma\cdot s_0 \ \ldots\ldots\ldots\ 12\,a)$$

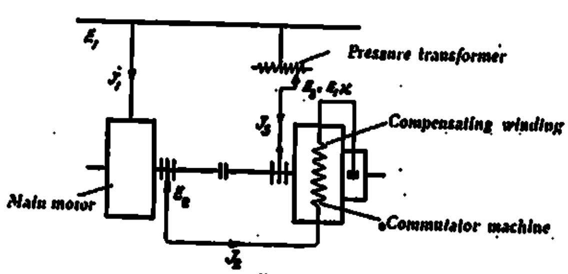


Fig. 4.

This is an exceedingly important result. It can be expressed in words as follows:

The necessary series voltage (in the ratio of speeds N_1/N_2 reduced to the primary side) is practically equal to 100 s_0 % of the total leakage reactance voltage of the primary current $I_1x_1\sigma$.

Lastly, as regards the phase displacement of the series voltage this can best be represented graphically as shown in figs. 2 a and b.

In fig. 2 a we have

$\dot{I}_{10}$ the primary current at no load, $p=0$ $(s=s_0)$

$\dot{I}_{1\infty}$ " " " " " " $p=\infty$ $(s=s_k)$

$\dot{I}_1$ " " " on load

$\varphi_\infty=\tan^{-1}\frac{x_\infty}{r_\infty}$

$\varrho_{2k}=\tan^{-1}\frac{r_2}{x_2s_k}$

$\dot{E}_{20}$ the secondary voltage at no load

$\dot{E}_2$ " " " on load

The auxiliary voltage $\Delta E'_2$ corresponds only to the current difference I_1-I_{10}.

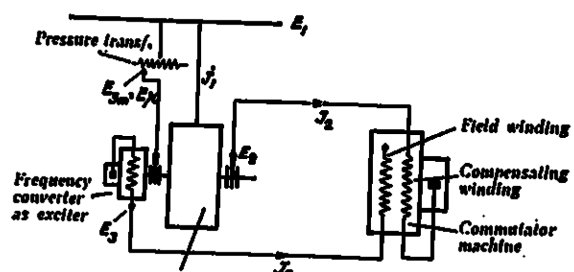


Fig. 5.

Fig. 2 b shows the voltage diagram on a somewhat different scale. In place of $\Delta E'_2$ we have shown the voltage with the same phase relation

$$\Delta E'_2\cdot\frac{1-\frac{s_0}{s_k}}{1-\frac{s}{s_k}}=-(\dot{I}_1-\dot{I}_{10})\,z_\infty s_0\frac{x_2+j\frac{r_2}{s_k}}{x_{21}} \ \ldots\ 13)$$

This voltage bears a constant relation to the primary current or, more correctly, to the current difference $\dot{I}_1-\dot{I}_{10}$; the extremity of the voltage vector accordingly describes as the load increases a curve of the same form as the primary current vector. In fig. 2 b this curve is a circle, the diameter of which in the current diagram is: $(\dot{I}_1-\dot{I}_{10})_{max}$ and accordingly in the voltage diagram

$$(\Delta E_{2max})\frac{1-\frac{s_0}{s_k}}{1-\frac{s}{s_k}}=(\dot{I}_1-\dot{I}_{10})_{max}\cdot z_\infty\cdot s_0\frac{\sqrt{x_2^2+\left(\frac{r_2}{s_k}\right)^2}}{x_{21}} \quad 13a)$$

The inclination of the two vectors is the angle $\varphi_\infty-\varrho_{2k}$. Knowing this connection, we are able to determine in magnitude and phase

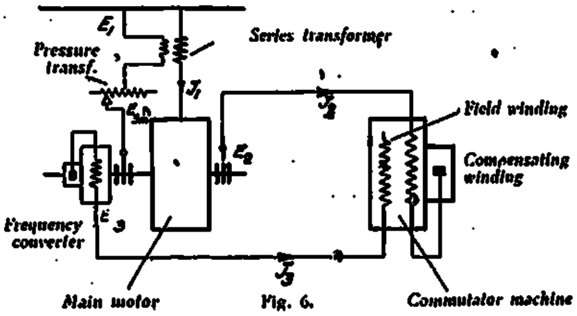


Fig. 6.

the component of the series phase compensating voltage which varies with the speed. Although it can clearly be seen from equations 12 and 13 we wish to point out particularly that $\dot{E}'_2$ and $\Delta\dot{E}'_3$ respectively, are of opposite sense for speeds under and over synchronism.

II. *Generation of the variable series phase compensating voltage with different cascade connections.*

The fact that the law governing series phase compensation was understood so late is very easily explained. In the oldest and, in fact, for many years the only kind of cascade connection which was used series phase compensation was obtained incidentally.

This system of connection which is shown in fig. 3 is known either as Kramer or Scherbius connection. The commutator machine is either directly coupled with the main motor ($s_k = 1$) or with another machine (commonly an asynchronous or synchronous generator) which keeps its speed nearly or exactly constant ($s_k = \infty$). The commutator machine has a compensating winding which supresses the armature reaction and a field winding (current $\dot{I}_3$) which supplies its main field. By the rotation of the armature conductors in this field, the voltage generated is:

$$\dot{E}_{32} = -j\dot{I}_3 c_{32}\left(1-\frac{s}{s_k}\right) \qquad 14)$$

which for our purpose can be put equal to the secondary voltage of the main motor. In the following $r_3 - x_3 s$ the resistance and reactance of the field winding and $\dot{E}_3 = \dot{E}_2\varkappa$ the terminal voltage of the field winding. The field current is then

$$\dot{I}_3 = \frac{\dot{E}_3}{r_3 - jx_3 s} = \frac{\dot{E}_2\varkappa}{r_3 - jx_3 s} \qquad 15)$$

Further we have, for no load, nearly enough

$$\dot{E}_2 = \dot{E}_{32} = \frac{c_{32}\varkappa}{x_3 s_0 + jr_3}\left(1-\frac{s_0}{s_k}\right)\cdot\dot{E}_2 \qquad 16)$$

and we obtain

$$\frac{c_{32}\varkappa}{x_3 + j\dfrac{r_3}{s_0}} = \frac{s_0}{1-\dfrac{s_0}{s_k}} \qquad 17)$$

On the other side from equations 1 and 2 we get:

$$\dot{E}_2 = \dot{I}_2(r_2 - jx_2 s) - j\dot{I}_1 x_{12} s$$

$$= \frac{\dot{E}_1 - \dot{I}_1(r_1 - jx_1)}{-jx_{21}}\cdot(r_2 - jx_2 s) - j\dot{I}_1 x_{12} s$$

$$= \frac{(r_2 - jx_2 s)}{-jx_{21}}\cdot\left[\dot{E}_1 - \dot{I}_1\left(r_1 - jx_1 + \frac{x_{12}x_{21}}{\dfrac{r_2}{s} - jx_2}\right)\right]$$

or

$$\dot{E}_2 = \frac{x_2 + j\dfrac{r_2}{s}}{x_{21}}(\dot{E}_1 - \dot{I}_1\cdot\dot{z})\cdot s \qquad 18)$$

wherein $\dot{z}$ denotes the apparent primary impedance of the main motor at slip s.

Thus we obtain

$$\dot{E}_2 \doteq \dot{E}_{32} = \frac{c_{32}\varkappa}{x_{21}}\,\frac{x_2 + j\dfrac{r_2}{s}}{x_3 + j\dfrac{r_3}{s}}\left(1-\frac{s}{s_k}\right)\cdot[\dot{E}_1 - \dot{I}_1\dot{z}] \qquad 19)$$

If we now limit the applicability of the calculations to large values of slip (*e.g.* $s > 0.2$) thus to the neighbourhood for which the importance of series phase compensation is greatest, we arrive at an exceedingly surprising discovery. Here we have with good approximation

$$(\dot{z})_{s>0.2} = \dot{z}_\infty = r_1 - jx_1\sigma$$

and

$$\left(\frac{x_2 + j\dfrac{r_2}{s}}{x_3 + j\dfrac{r_3}{s}}\right)_{s>0.2} = \frac{x_2}{x_3}$$

Using these approximate equations and equation 17 we obtain as a final formula

$$\dot{E}_{32} \doteq (\dot{E}_1 - \dot{I}_1\dot{z}_\infty)\cdot s_0\,\frac{1-\dfrac{s}{s_k}}{1-\dfrac{s}{s_k}}\cdot\frac{x_2 + j\dfrac{r_2}{s}}{x_{21}} \qquad 20)$$

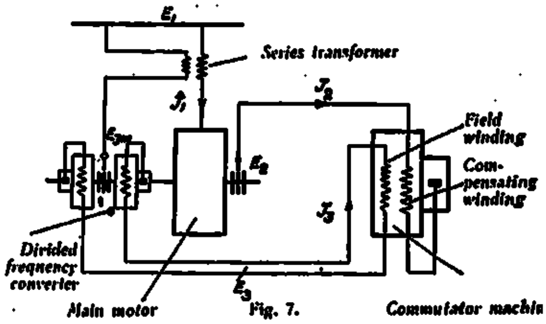


Fig. 7.

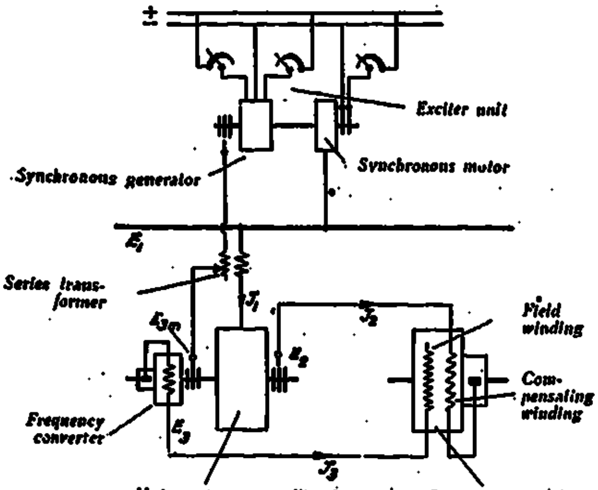


Fig. 8.

In this equation the second term is precisely in agreement with the series phase compensating voltage according to equation 12. Cascade connection as indicated in fig. 3 accordingly generates, when the value of the slip is large, just the correct series voltage without it being necessary to take any other special precautions to ensure it. Herein lies the reason for this investigation being first undertaken in quite recent years. The transformation from E_2 to E_3 can naturally be carried out in different ways (compare the modern Brown Boveri connection with exciters); the main point is that $\dot{E}_3$ is made proportional to $\dot{E}_1$, *i.e.* that the field winding is in one way or another excited from the sliprings of the main motor.

During the last few years, however, two firms, namely Asea and SSW, have brought out new systems of cascade connection in which the commutator machine is magnetised in an entirely different manner.

Fig. 4 shows the scheme of connections for the SSW cascade system. The field of the commutator machine is supplied by a multiphase winding connected to the sliprings. If both the main machines are direct connected ($s_k = 1$) the frequency of the exciter voltage ($\dot{E}_3$) is equal to the frequency of the supply. It is accordingly possible to regulate the speed of the main motor by the help of a transformer connected to the primary supply, having an adjustable secondary winding which is only designed with an output equal to the magnetisation.

By this coupling a voltage, as shown earlier (equation 14), is impressed on the secondary circuit of the main motor

$$\dot{E}_2 \equiv \dot{E}_{32} = -j\dot{J}_3 c_{32}\left(1-\frac{s}{s_k}\right)$$

with the difference that the field current is determined by

$$\dot{J}_3' = \frac{\dot{E}_1\varkappa}{r_3 - jx_3} \quad \ldots\ldots\ldots\ldots\ldots \ 21)$$

So that we now obtain

$$\dot{E}_2 = \dot{E}_1\varkappa\frac{c_{32}}{x_3 + jr_3}\left(1-\frac{s}{s_k}\right) \quad \ldots\ldots\ldots \ 22)$$

We see that this voltage is quite constant and in addition contains no "series voltage."

The conditions are precisely similar with Asea cascade connection, the scheme of which is shown in fig. 5. The commutator machine is wound in the same manner as with Kramer or Scherbius cascade connection *i.e.* it has a separate field winding 3 on the stator which must be supplied at the slip frequency. The exciter voltage is generated in a small frequency converter which is connected with the main motor for relative synchronism and has three windings. The slipring winding is supplied with a voltage $\dot{E}_{3m} = \dot{E}_1\varkappa$ at the frequency of the supply. This voltage is transformed in the commutator winding to a voltage $j\dot{E}_{3m}\frac{r_3}{x_3}$ and in the stator winding to a voltage $E_{3m}\cdot s$; both voltages alternate at the slip frequency. The magnetising current $\dot{J}_3$ is then:

$$\dot{J}_3 = \frac{\dot{E}_3}{r_3 - jx_3 s} = \dot{E}_1\varkappa\cdot\frac{j\frac{r_3}{x_3}+s}{r_3 - jx_3 s}$$

$$= \frac{j\dot{E}_1\varkappa}{x_3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ 23)$$

and the rotation voltage of the commutator machine

$$\dot{E}_{32} = \dot{E}_2 = -j\dot{J}_3 c_{32}\left(1-\frac{s}{s_k}\right) = \dot{E}_1\varkappa\frac{c_{32}}{x_3}\left(1-\frac{s}{s_k}\right) \ldots \ 24)$$

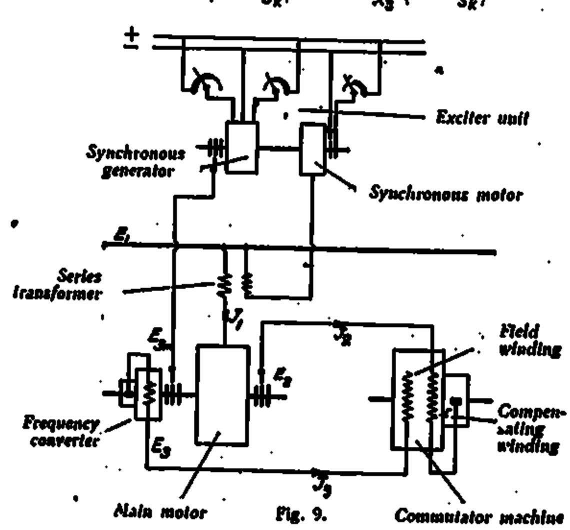


Fig. 9.

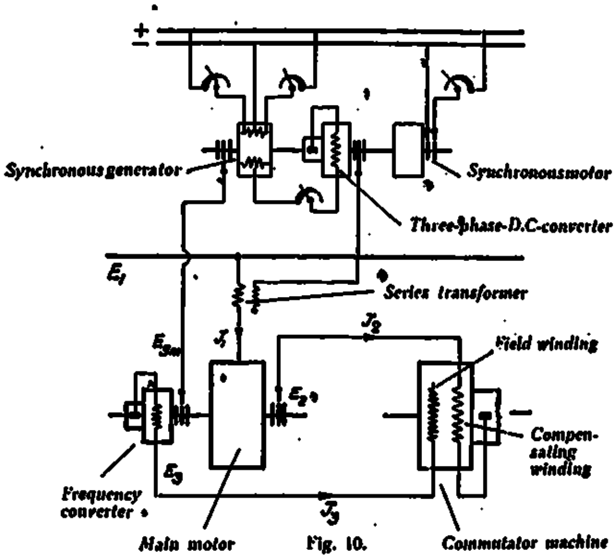


Fig. 10.

Accordingly even here the variable component dependent on the no load speed which is required for series phase compensation, is so far absent.

What we now have to do is to supply this want, making use of the law which has been developed for the series phase compensating voltage and in the following we shall describe some connections which we have developed for this purpose. Most of these can also be made use of with the SSW cascade system.

If the speed of the main motor is regulated through a pressure transformer with variable voltage ratio which is connected to the supply (figs. 4 and 5) the necessary series voltage can be developed most simply by the help of a series transformer (fig. 6). The primary winding is traversed by the primary current $\dot{I}_1$ of the induction motor and the secondary side is in series with the primary winding of the pressure transformer. If the mutual reactance between the windings of the series transformer is made equal to $z_{\infty}^{\bullet}$ equation 12 is fulfilled for all values of speed. The pressure transformer can be eliminated and at the same time continuous speed regulation obtained if the frequency converter is divided into two machines, the stators of which can be turned in opposite directions (fig. 7). In this manner we obtain the same effect as we should with a double induction regulator but with the difference that not only the magnitude E_3 of the field voltage is transformed but also the frequency.

The conditions are not so simple if the variable magnetising voltage E_{3m} is generated by a separate exciter unit commonly consisting of a synchronous motor and a synchronous generator (fig. 8). So as to be able to regulate the magnitude of the generator voltage and the phase displacement at the same time, the generator is in general furnished with two field windings which are displaced from one another by half the pole pitch. If we wish to make use of a series transformer instead of a frequency converter with this system of connection also then the ratio of the transformer must be regulated at the same time as the generator voltage E_{3m} either continuously or step by step.

To eliminate this complication we can connect the series transformer in circuit before the synchronous motor. In accordance with fig. 2, what we chiefly require is that with increased load the vector of the applied secondary voltage $\dot{E}_2$ is retarded by a certain angle ψ so that the phase compensating component at right angles to $\dot{E}_1$ is raised for increasing load at speeds below synchronism, and lowered for speeds above synchronism. If the synchronous motor as shown in fig. 9 is made with one field winding only, the effect of the series transformer connected in circuit before it, is that for a certain load the exciting voltage $\dot{E}_{3m}$ is retarded by the same angle ψ at all speeds. If we use two field circuits for the motor, as for the generator ψ can also be varied in close agreement with fig. 2. The advantage of this system of connection as compared with fig. 8 is that the ratio of the series transformer does not require to be variable.

When large units are in question it is possible to employ still more elaborate methods of regulation. The most obvious suggestion would be to use an automatic regulator for controlling the reactive power. The AEG and probably other firms, construct such regulators by which the current in one field winding of the generator is so regulated that the reactive power of the main motor is either kept constant or else altered proportionally with the active power. The series phase compensating voltage is then produced in the generator itself and the series transformer becomes superfluous. If two such

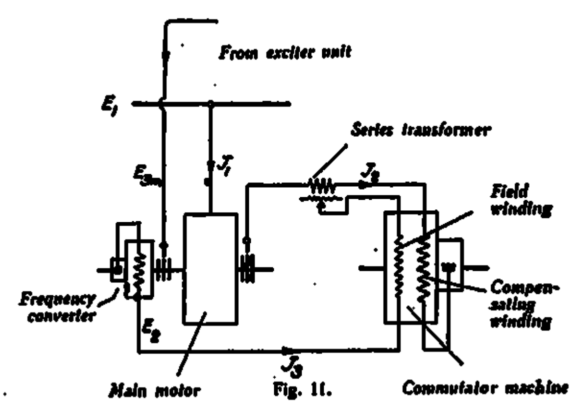


Fig. 11.

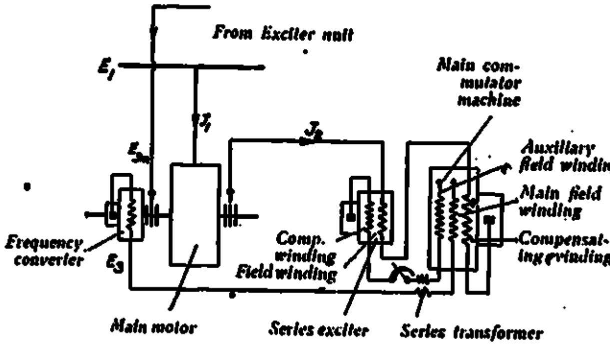


Fig. 12.

regulators are employed, one for each field winding, the active and reactive power of the main motor can be independently regulated.

Lastly, we can make use of a machine compounded on the Danielson system or some similar frequency converter so as to transfer the generation of the series phase compensating voltage to the field circuit of the generator (fig. 10)*. The slipring winding of the converter is then excited through a series transformer with a current which is proportional to the primary current of the main motor. The commutator is best provided with multiphase brush gear which is connected through a variable resistance to an additional field circuit on the generator, also multiphase. Every alteration of the magnitude of the main current (I_1) and phase is then varied by proportional alteration (in magnitude and phase) of the auxiliary field of the generator and the auxiliary voltage thereby produced is the desired series phase compensation. The magnitude of this is altered as indicated in equation 12 proportionally to p_0 by connection or disconnection of the above mentioned resistance in the auxiliary field of the generator at the same time as the speed of the main motor is altered by regulating the resistance in the main field circuit of the generator.

All the systems of connection so far discussed deal with variable series phase compensation from the primary current of the main motor, and in most cases this is the most suitable manner of carrying it out. Naturally, however, there is nothing to prevent us from working instead from the secondary current. For small units an arrangement in accordance with fig. 11 may be considered satisfactory. This only differs from fig. 8 in that the variable ratio series transformer is connected in the secondary circuit instead of in the primary circuit of the main motor. In the case of large units it would be better to generate the series voltage in a separate series exciter of the same type as the main commutator machine (fig. 12). The field winding is traversed by the secondary main current, armature current being suppressed by a compensating winding. This machine excites a separate field winding on the stator of the main commutator machine with a current I_4 which by means of a series resistance is made to depend on the no load speed of the main motor. A small series transformer suppresses the inductive coupling which connects the two field circuits in the main commutator machines.

It would be easy to suggest several other systems of connection which would give the same result; the examples given, however, should make the problem of regulation clear enough from a sufficient number of points of view. Special cases naturally demand special precautions which hardly fall within the scope of the present brief article.

L. Dreyfus.

* The frequency converter in fig. 10 is of similar construction to the commutator machine in fig. 4. The stator winding (compensating winding) can however be omitted.

SUDDEN SHORT CIRCUIT OF SYNCHRONOUS MACHINES.

Proposal for Formulation of Guarantees.

If a synchronous machine is suddenly short circuited a current is obtained which shows the following characteristic qualities. See fig. 1.

1) The current curve can be divided by a centre line, "the D.C. component", and round this is a fluctuation having the periodicity of the machine, "the A.C.component".

2) The magnitude of the D.C. component ("the asymmetry") depends on the moment when the short circuit occurs; its value at the instant of short circuit may lie anywhere between zero and the maximum amplitude of the A.C. component.

3) Both components are damped, the D.C. component usually the more strongly and being asymptotic to the zero line, the A.C. component having the permanent short circuit as a final value.

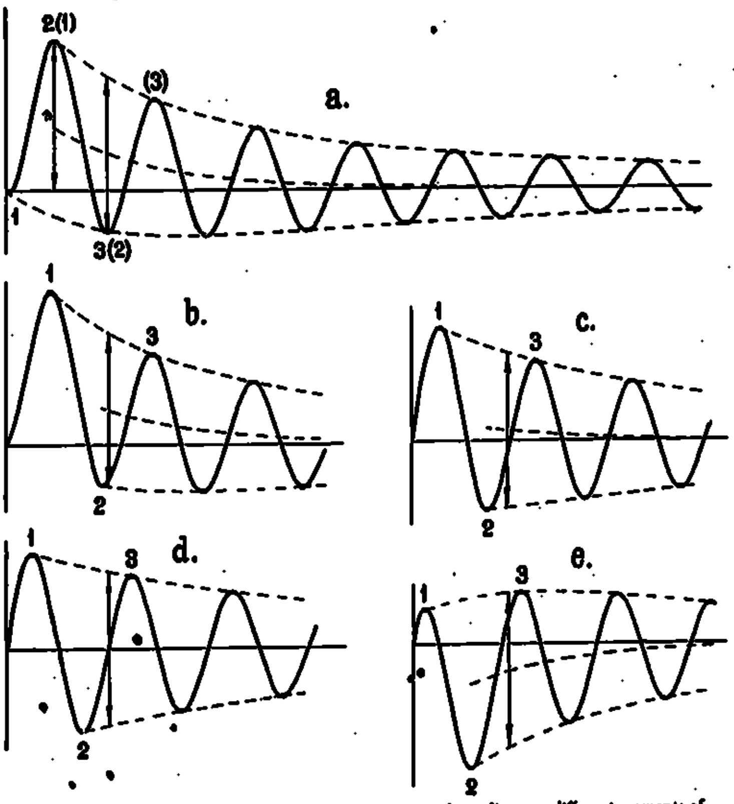


Fig. 1. The shape of the short circuit current curve depending on different moments of short circuit: a) completely asymmetrical, b) not fully asymmetrical, d) symmetrical current curve.

We can, assuming constant damping coefficients and neglecting higher harmonics, write

$$I = f\cdot A\cdot e^{-\gamma t} + [(A - B)\cdot e^{-\alpha t} + B]\cdot \cos\omega(t - t_0) \quad (1)$$

where f is a factor for "asymmetry" lying between 0 and $\pm$ 1 and t the time after the instant of short circuit; t_0 is the time value for the first positive maximum of the current wave.

When a synchronous machine is ordered, a guarantee is sometimes demanded that the instantaneous short circuit current in the most unfavourable case will not exceed a certain given value. When the machine is completed a short circuit test is made and an oscillogram made of the current variation. As in general it is not possible to control the instant at which the short circuit will take place, in relation to the voltage wave, it is a matter of pure chance if the current curve is at a maximum so that the worst current maximum is directly measured by the oscillogram.

To carry out repeated short circuits, until such an asymmetrical curve is obtained, would be to subject the machine to unnecessary stresses. It is, accordingly, desirable to be able to formulate a guarantee for the magnitude of the short circuit current in such a way that by means of a single oscillogram taken at any instant it is possible to ascertain that the guarantee has been met.

As it may happen that the current curve is nearly symmetrical, so that the D.C. component approaches 0, the guarantee value should in some way be made independent of the damping of the D.C. component. This can be accomplished if we measure only the A.C. component, even in the case of an asymmetrical curve. If a tangent curve is drawn to all the positive current peaks and a similar curve to all the negative peaks we can measure the overall double amplitude of the A.C. component as the distance between the tangent curves. Extrapolation by extending the tangent curves backwards on the respective sides behind the first peaks might be arbitrary and should accordingly be avoided. The earliest certain value of the double amplitude is obtained from the second peak of the curve (the numbering is not affected by the direction of the maximum points) opposite the tangent curve between the peaks 1 and 3. As the current peak no. 1 may occur about $1/2$ period after the instant of short circuit, see fig. 1b, the peak no. 2 takes place, in the limiting condition, a complete period after the instant of short circuit. It is of interest to know how the amplitude value measured in this way compares with the

greatest possible short circuit current actually occurring in practice.

In the neighbourhood of $t=0$ the expression $e^{-\alpha t}$ can be written

$$e^{-\alpha t} \approx 1 - \alpha t$$

and thus equation (1) can be put in the form

$$I = f \cdot A\,(1-\beta t)+[(A-B)\,(1-\alpha t)+B]\cdot \cos\omega\,(t-t_o)$$

$$I = f \cdot A\,(1-\beta t) + A\,(1-\gamma t)\cdot \cos\omega\,(t-t_o) \;\ldots\; (2)$$

$$\gamma = \frac{A-B}{A}\cdot\alpha$$

The largest current maximum occurs for $f=1$ at an instant approximately $\frac{1}{2}$ period after the instant of short circuit. See fig. 1 a. Then

$$I = A\left(1-\frac{\beta}{2\nu}\right)+A\left(1-\frac{\gamma}{2\nu}\right)$$

$$= A\left(2-\frac{\beta}{2\nu}-\frac{\gamma}{2\nu}\right)\;\ldots\ldots\ldots\ldots\; (4)$$

For the case just considered where the first maximum occurs about $\frac{1}{2}$ period after the instant of short circuit we obtain the double amplitude of the A.C. component for $\omega t = \frac{1}{\nu}$

$$I' = 2A\left(1-\frac{\gamma}{\nu}\right)\;\ldots\ldots\ldots\ldots\ldots\; (5)$$

This is equal to or greater than the greatest possible single maximum, if

$$2A\left(1-\frac{\gamma}{\nu}\right) \geqq A\left(2-\frac{\beta}{2\nu}-\frac{\gamma}{2\nu}\right)$$

$$\frac{\beta}{2\nu}+\frac{\gamma}{2\nu} \geqq 2\frac{\gamma}{\nu}$$

$$\beta \geqq 3\gamma \;\ldots\ldots\ldots\ldots\ldots\ldots\; (6)$$

Investigations carried out on a number of short circuit oscillograms from different machines show that

$$\frac{\beta}{\alpha} \approx 5 \text{ to } 20$$

or on the average 10, if the damping factor is calculated from the damping observable after approximately 0.2 secs. However, in machines having solid rotor poles and pole shoes the A.C. component in the first part of the current curve is much more strongly damped than in the continuation. The damping factor for the D.C. component is no doubt much more constant. This means that for the first peaks of the current curve β/α can be considerably less than about 10; β/γ is somewhat greater than β/α.

From the available oscillograms giving the short circuit current obtained for Asea synchronous machines we have selected all those which show practically full asymmetry and have compared the double amplitude after 1 period with the actual greatest maximum above the zero line. The result has given the following eight values obtained from 4 different machines.

The double amplitude/the greatest maximum = 0.96 1.08 0.95 0.98 0.94 0.93 1.03 0.94. The mean value is 0.976. All these machines have solid poles. From an investigation of all published oscillograph records taken from machines of unknown rotor construction, but presumably chiefly having solid poles, we have obtained a mean value of 0.99. Machines with fully laminated magnetic circuits would not show the above property with respect to damping, and the mean value for these presumably lies above 1.0.

It is, accordingly, proposed that the following rules should be made regarding the guarantee and measurement of sudden short circuit current:

All positive current peaks in the oscillogram should be joined by a tangent curve and the negative peaks similarly treated. The distance between these tangent curves measured at a point 1 period after the instant of short circuit shall be assumed to be the double amplitude value of the sudden short circuit current ($2\sqrt{2}\cdot I_i$). This value is compared with the double amplitude of the normal load current ($2\sqrt{2}\cdot I$) in order to give *the percentage value of the sudden short circuit current* ($100\ I_i/I$). When the *reactance* (X_i) *for sudden short circuit* is given, this is understood to mean the phase voltage of the machine before short circuit, assuming no load, divided by the sudden short circuit current; both voltage and current are measured as double amplitude or as effective value ($X_i = E/I_i$). This may be shortly called the *initial reactance*.

The advantages of using the above procedure are as follows:

1) Full independence is secured of chance asymmetry in the short circuit current curve.

2) No extrapolation need be made.

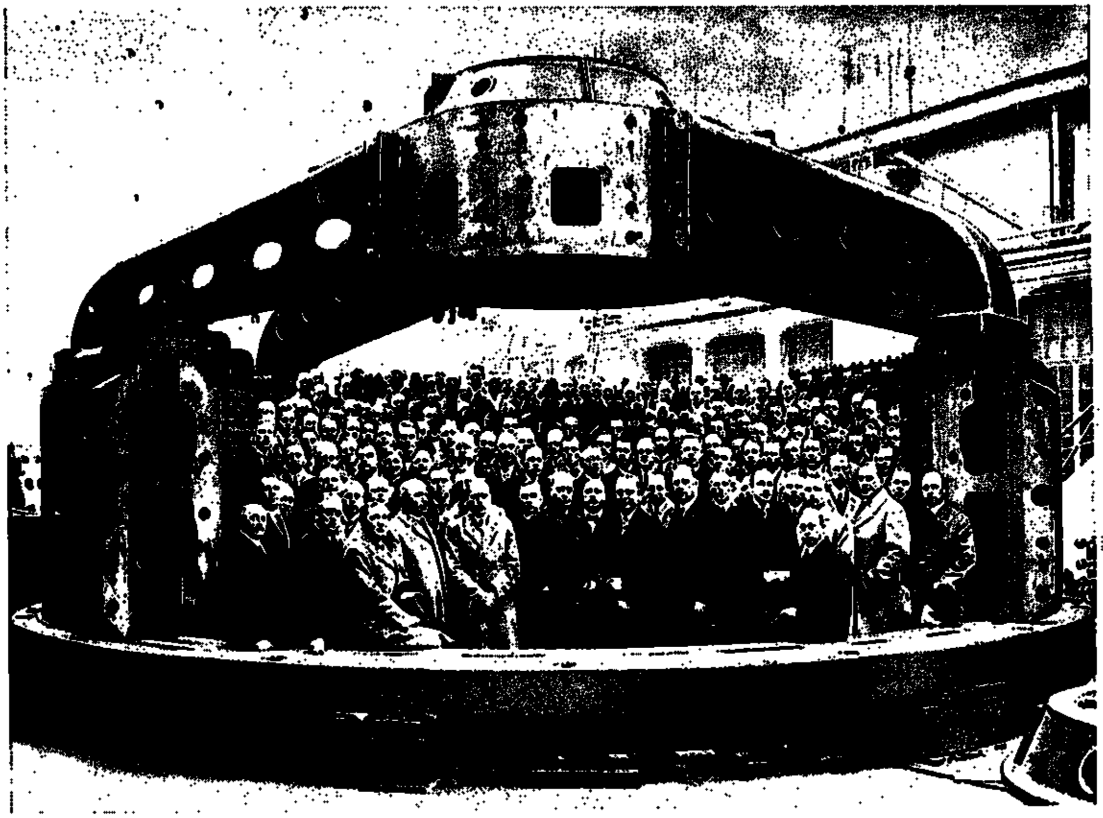
3) The observed value is very close to the actual greatest possible amplitude.

4) The percentage value of the current has a definitive and sensible meaning (a double amplitude is compared with a double amplitude).

5) The reactance value also is fully determined whereas, formerly, two meanings were frequently confused when speaking of reactance.

J. Wennerberg.

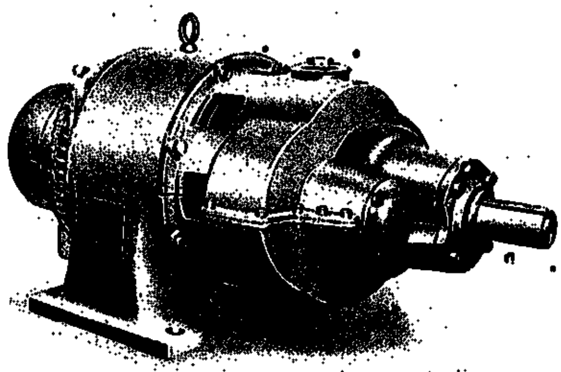
A VISIT TO ASEA.



The Svenska Elektricitetsföreningen (Swedish Power Station Engineers Association) recently held their annual meeting in Vesteras, when the above photograph was taken of the Members together with Delegates of the electrical branch of the Svenska Teknologföreningen, (Swedish Technical Society) who were visiting Asea at the same time. — The photograph is taken in the stator of one of the three vertical three-phase generators for the Imatra, Finland, the machine being one of 24,000 kVA at 125 r.p.m., 50 periods, 10,000– 11,000 volts. This machine when completed will weigh 400 tons.

FRONT PAGE.

In 1924 the Società Generale Elettrica dell'Adamello, of Milan, ordered from Asea three 10,000 kVA transformers for 117,000/70,000 volts, 42 periods for their sub-station at San Polo. This was the first order for large transformers which had been received by Asea from Italy and was obtained in the face of considerable competition from American and other European firms, thus giving an indication of the reliance placed on the name of Asea in the world's markets. Sometime later the same Company ordered two further similar transformers bringing up the total to five 10,000 kVA transformers. The illustration on the front page shows the three original transformers immediately after erection and ready for setting to work. The transformers are water cooled, the water circulating through copper spirals placed in the upper part of the thanks which are specially designed to accomodate them. These transformers are used to connect the Company's new 125 kV line from various power stations in the Alps with the old 70,000 kV network, and are provided on the 70 kV side with extra tappings brought through the cover, giving approximately 5 % voltage variation.



Three-phase motor type MKA with double reduction gear type VD.

ECONOMY!

Formerly machine shops and factories gave the impression of a forest of belt drives which gave rise to losses in power, space, time and also endangered the lives of workmen.

Now in modern shops these are replaced by Asea geared motors which transform the earlier losses into corresponding gains and thereby radically improve the working economy.

Asea geared motors increase the total efficiency of a plant and allow of increased production, with the same expenditure of power or a considerably reduced expenditure of energy for similar production.

They set free a large amount of space for productive purposes and at the same time, due to the elimination of belts, allow of better lighting and greater comfort for the workmen which leads directly to increased production.

Saving of time also arises as the necessity for oiling and maintenance is reduced to a minimum. Total maintenance costs are greatly reduced and working is much simplified while reliability is as high as can posibly be imagined and accidents are at the same time practically cut out.

Can you afford to disregard these advantages?
If not, write to our nearest representatives
for fuller particulars.

ASEA

VESTERAS — SWEDEN

Vesteras, Sweden, 1927. Vestmanlands Allehanda Printing Co.

ASEA-JOURNAL

ALLMANNA SVENSKA ELEKTRISKA A.B.
VESTERAS — SWEDEN

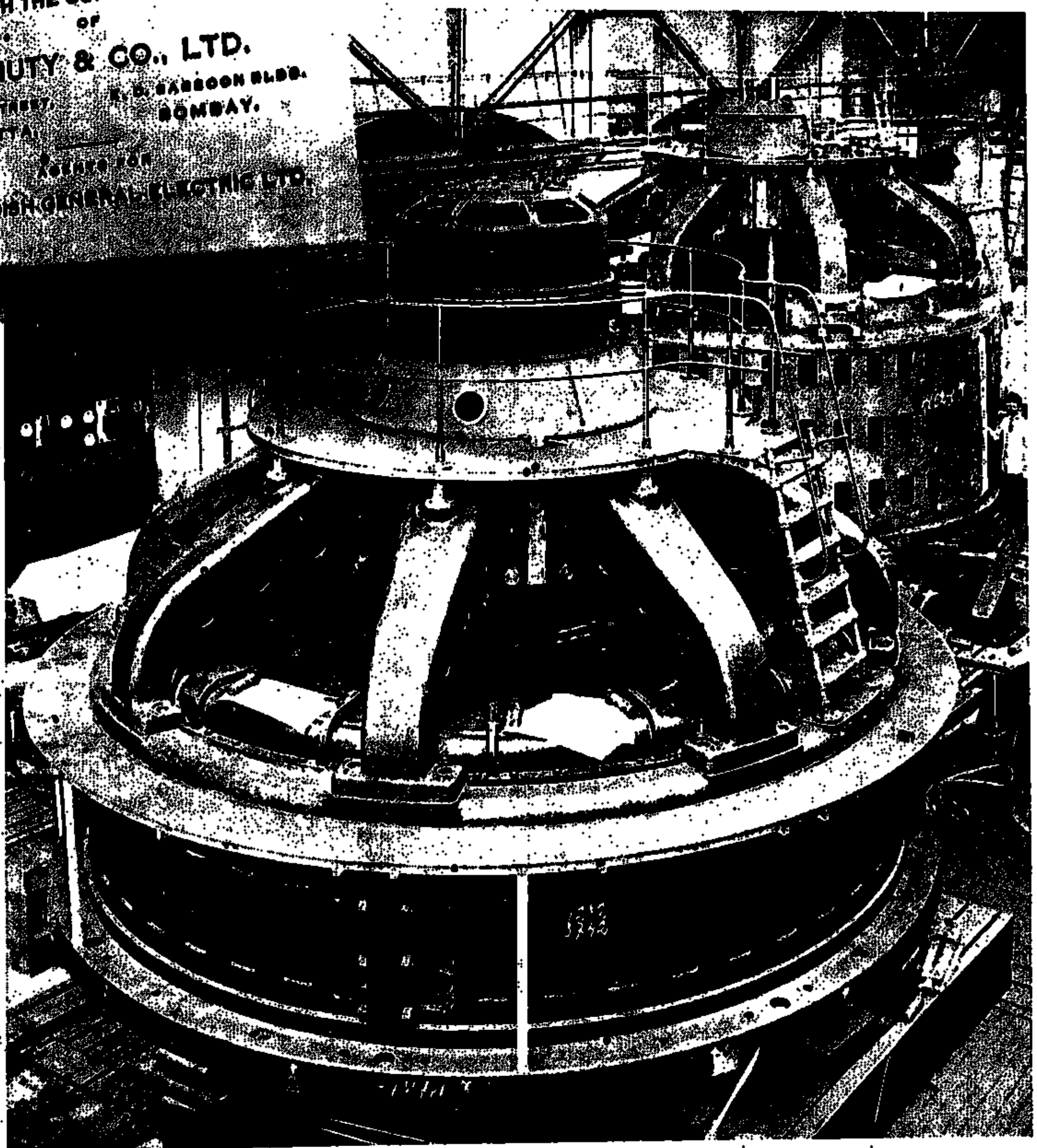
SWEDISH GENERAL ELECTRIC LTD
8. CHANCERY LANE—LONDON

MONTHLY REVIEW

VOL. IV
1927

All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesteras, Sweden.
is given to reprint articles or extracts from this journal on that the name — Asea-Journal — is clearly stated.

SEPT.
No. 9



Interior from the test room in Asea large machine factory. One 12,500 kVA and one 18,000 kVA A.C. generator.

SOME NOTES ON THE TECHNICAL DATA REQUIRED FOR THE DESIGN AND CONSTRUCTION OF FANS AND VENTILATORS.

Fans and ventilators are very largely used in modern engineering work, when it is necessary to circulate air or other gases. The question of their type and design has accordingly become of considerable importance. In the case of fan equipments, especially those which must be carefully investigated before construction, it is very important that the fans should be suitable for their particular service and should fulfil their guarantees as regards capacity, power requirements, *etc.* If the builders are provided in advance with all necessary information for the design and construction, or when the whole installation is undertaken by the fan builders, no great difficulties usually arise. As, however, the customer often considers a few leading technical particulars to be sufficient for designing fans, we wish to show in the following that this is not so and that a number of factors, usually disregarded, may exercise an important bearing on the working of the fan unit.

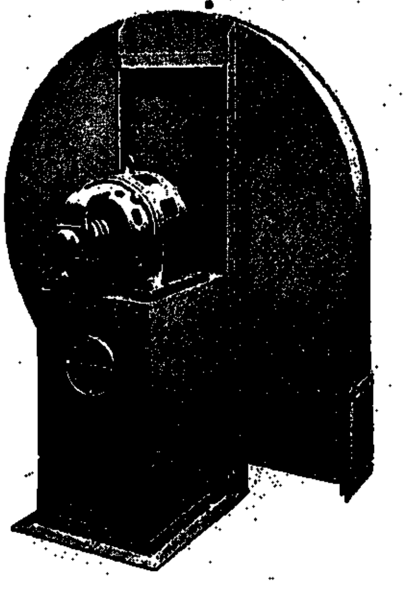


Fig. 1. High pressure fan, type HFB 11.

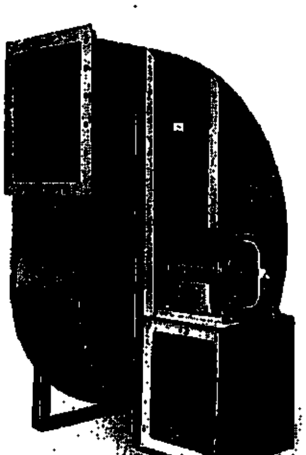


Fig. 2. Turbo ventilating fan, type TV.

It is, of course, important that the manufacturer should obtain accurate information as to the purpose for which the fan will be used, for example if it is for ventilation, for the transport of grain or for forced draught in a boiler house. In addition, particulars as to the most suitable speed must be given, or data provided, from which a suitable speed may be chosen, *e.g.* in the case of electric drive, particulars of the supply should always be stated. It may be pointed out in this connection, that when it is particularly desired that fans should run silently, a relatively low speed should be used. Having settled the particulars mentioned above, the manufacturer should ascertain the pressure desired when working at full capacity. The capacity is usually stated in cubic feet per hour, minute or second. If no information as to temperature is given, it is usual to assume an ordinary room temperature (15° or 20° C) and normal barometric pressure. The quantity of air delivered by a fan can be determined in accordance with the conditions existing, either by anemometer, by Pitot tube in combination with a micromanometer, or some similar arrangement. The method employing a Pitot tube and micromanometer is to be recommended, particularly when exact results are required. The supply pressure is commonly stated and measured in inches water column. One inch water column corresponds approximately to 0.036 lbs. per square inch and is thus an exceedingly small pressure compared, for example, with a pressure of 1 atmosphere. The pressures which are in question in fan work seldom exceed from 30 to 40 ins. water column.

As regards the specified delivery pressure of

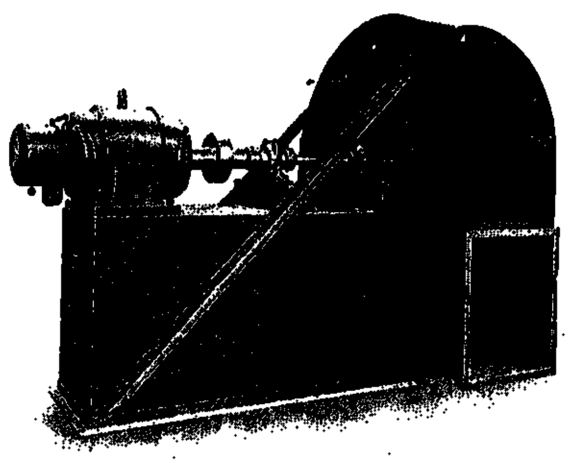


Fig. 3. Fan for smoky gases, type RE, with water cooled bearings.

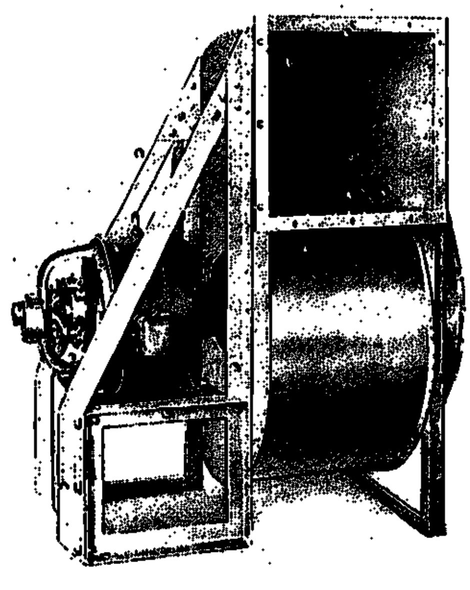


Fig. 4. Sirocco fan, type SF.

a fan it should be noted that this may often have different meanings. Before dealing with the more usual of the different conceptions however it will be of assistance to mention the following. If a quantity of air moves along any duct (the specific volume and specific weight of the air being assumed constant), as shown in fig. 5 the difference in total pressure between two sections in the duct represents the power gained or lost per unit of volume between them. If the difference in total pressure is assumed to be h inches water column, this can be expressed by the formula:

$$h = p_2 + \left(\frac{v_2}{v_0}\right)^2 - p_1 - \left(\frac{v_1}{v_0}\right)^2$$

in which p_2 and p_1 are the static over or under pressures in inches of water column, at the respective sections A and B in the figure, v_2 and v_1 = the average velocity of air in feet per second at A and B, v_0 = velocity corresponding to unit pressure.

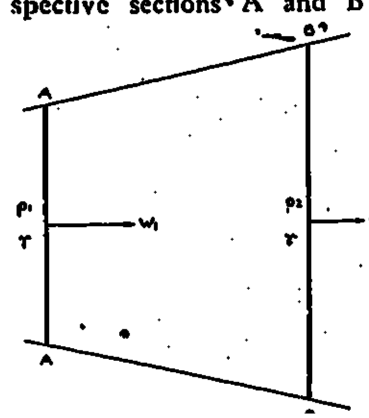


Fig. 5.

The expressions $\left(\frac{v_2}{v_0}\right)^2$ and $\left(\frac{v_1}{v_0}\right)^2$ are called velocity head or dynamic pressure.

The formula can be applied to a fan, where it is possible to assume with sufficient accuracy for practical purposes, that the air has constant specific volume during the working process inside and outside the fan.

If the fan draws air directly from the open, the speed of the air at a point remote from the intake is = 0 and there is neither over- nor underpressure at that point. If there is no pipe or duct to cause losses on the way to the intake, we have between any two sections on the intake side:

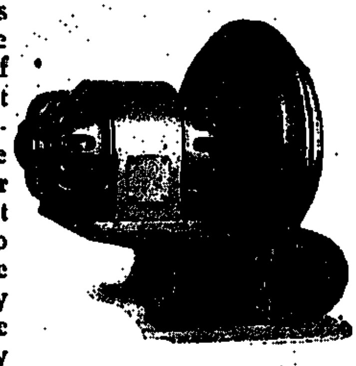


Fig. 6. Blower, type HF.

$h \approx 0$, and the formula given above assumes the form:

$$p_1 + \left(\frac{v_1}{v_0}\right)^2 = p_2 + \left(\frac{v_2}{v_0}\right)^2$$

If the speed at some considerable distance from the intake is v_1 and ≈ 0, then also $p_1 \approx 0$, and we have $p_2 = -\left(\frac{v_2}{v_0}\right)^2$. At every section on the intake side at which the speed is not zero there accordingly exists a vacuum equal to the velocity pressure $\left(\frac{v_2}{v_0}\right)^2$.

If the fan intake is a duct with some arrangement causing pressure losses, such as heating batteries, air filters, *etc.* there would naturally be a greater vacuum in the duct than that corresponding to the velocity pressure. With a fan, which works with a free outlet the static pressure at a section through the outlet is ≈ 0. If the outlet is connected to piping giving rise to friction losses, *etc.* this causes in general a static overpressure at the delivery side.

The formula can be applied also between the inlet and outlet sections. The total pressure difference is then approximately the same as the increase in energy

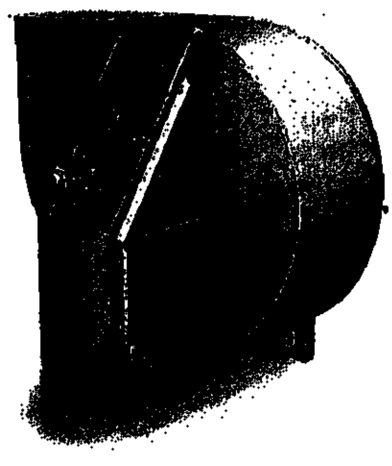


Fig. 7. Turbo ventilating fan, type TV.

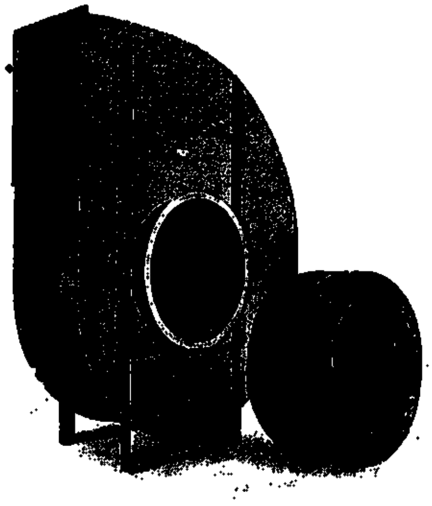


Fig. 8. Turbo ventilating fan, type TV.

occurring in the current of air per unit of volume, while the average value of v_1 and v_2 and p_1 and p_2 are used. If the total difference in pressure obtained:

$$h = p_2 + \left(\frac{v_2}{v_0}\right)^2 - p_1 - \left(\frac{v_1}{v_0}\right)^2$$

is multiplied by the quantity of air, which is assumed to be Q cu. ft./sec. the product Q × h is equal to that part of the power supplied to the fan, measurable between the inlet and outlet sections, in ft. lbs/sec. or expressed in h.p. $= \frac{Qh}{550}$.

Many firms give, in their lists and capacity tables for fans, the total pressure difference which is often only referred to as "total pressure"; and in Asea lists covering Schlotter ventilators, turbo ventilating fans, forge blowers, *etc.* this pressure is used. Some firms and customers, however, give a pressure which cannot be expressed by the formula used above, but intend by pressure a "static pressure" which, in most cases, is equal to the static over-pressure which could be maintained, with the desired delivery, at the outlet, if the fan were used as a pressure fan with free inlet.

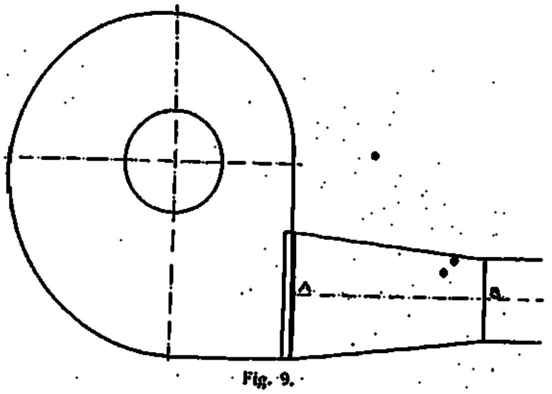


Fig. 9.

As misunderstanding regarding pressure often occurs, it is very necessary that in all technical particulars regarding fans a clear statement should be made as to whether the required pressure is looked upon as *total pressure* or *static pressure*. In order that the desired result shall be obtained, it is however also essential that a number of other conditions not yet mentioned should be taken into consideration. Some information regarding these will be given below.

Assume, for example, that the air capacity and the static pressure are specified for a pressure fan which, when installed, is to be connected to a pipe line with a smaller cross sectional area than the outlet opening of the fan, as indicated in fig. 9.

On the basis of the data given, the manufacturer can only design the fan so, that it will deliver the required volume of air at the required pressure represented by static over-pressure at the outlet. The customer may, however, assume that this pressure applies at section B, where the delivery piping commences. If we disregard losses in the connecting piece from A to B

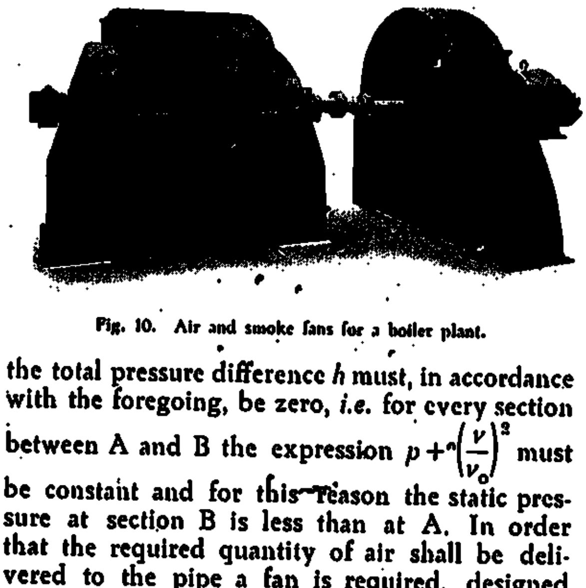


Fig. 10. Air and smoke fans for a boiler plant.

the total pressure difference h must, in accordance with the foregoing, be zero, *i.e.* for every section between A and B the expression $p + \left(\frac{v}{v_0}\right)^2$ must be constant and for this reason the static pressure at section B is less than at A. In order that the required quantity of air shall be delivered to the pipe a fan is required, designed for a considerably higher static over-pressure at the outlet A, in order that the static pressure drop along the path to B may not be greater than to give the intended static over-pressure at B. As the fan is now arranged, we shall obtain, if the speed remains constant, a smaller quantity of air than that desired for delivery into the pipe line. Fans in general have the common characteristic that they are unable to give more than *one pressure* for a given air quantity and at a constant speed.

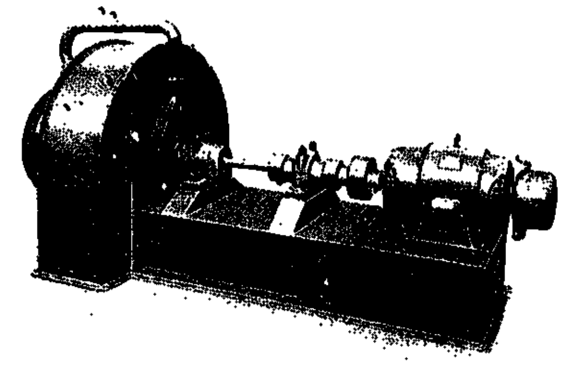


Fig. 11. Exhaust fan for poisonous gases; with special tightening device.

If, for a certain quantity of air, the resistance in the pipe line is greater than the fan can meet, the quantity of air delivered is automatically reduced to a value corresponding to the new air resistance, which is produced by the smaller air velocity and which the fan can overcome after the alteration in delivery volume. The friction losses, *etc.* occurring in the connecting piece between the fan and the pipe line further help to diminish the quantity of air. If the customer had stated the size (diameter) for the sectional area at B at which point he calculated that the static pressure must exist and, in addition, the space which could be allowed for the fan together with any connecting piece that might be necessary, the manufacturer would clearly have been able to design the fan for the exact pressure which it would have to develop to give the desired capacity.

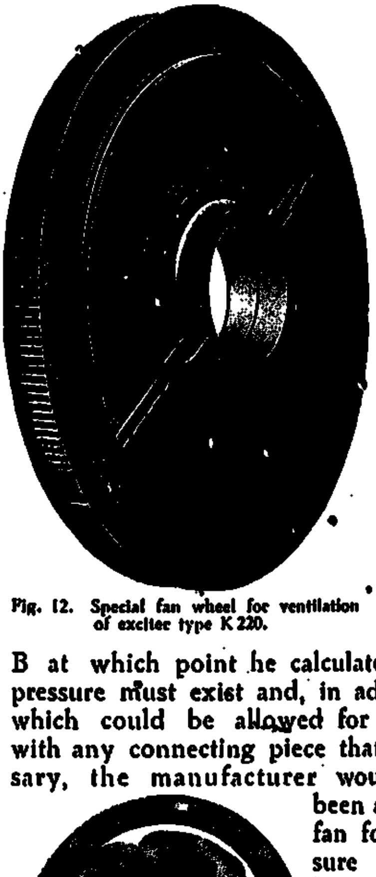


Fig. 12. Special fan wheel for ventilation of exciter type K 220.

Similar unexpected results may occur, if the connection is made in some manner different from that given in the above example, and the same applies when connecting fans to suction pipes.

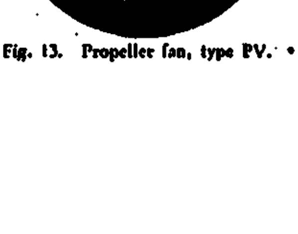


Fig. 13. Propeller fan, type PV.

What we have said above applies to fans in conjunction with pipe lines. Fans are often used without such pipe lines or ducts, for example where air is to be supplied or withdrawn from a room by a ventilator placed in an opening in the wall.

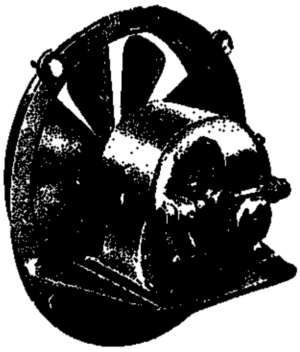


Fig. 14. Propeller fan, type VV.

In such a case the losses are not chiefly friction losses but dynamic losses. Pressure may suitably be regarded here as being the static pressure difference on the two sides of the wall in which the fan is working, measured between sections sufficiently large so that the influence of velocity pressure can be neglected. This static pressure difference is clearly independent of the dimensions of the ventilator, so that this can be manufactured without difficulty, if only the capacity and the correct pressure is stated. In cases where the customer has some special requirements regarding the size of the ventilator, having regard to the space available, *etc.* these can be met without trouble and when designing the ventilator, it should also be remembered that a fan of small diameter and running at a high speed requires more power to drive it than a fan of the same capacity with a larger diameter and lower speed.

What we have said above will make it clear that complete and exact technical particulars are of great importance, if suitable fans for different purposes are to be obtained. The technical data, which must of necessity be used in designing fans, can be summarised as particulars covering:

1) The purpose for which the fan is to be used.

2) Suitable speed, or particulars from which the manufacturer can make a choice of the speed, and if an electric motor is to be used

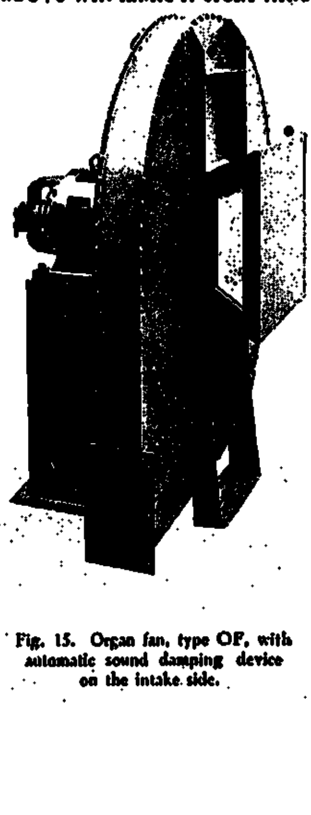


Fig. 15. Organ fan, type OF, with automatic sound damping device on the intake side.

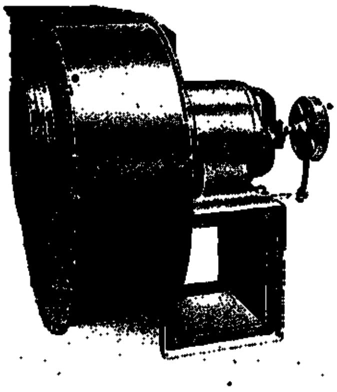


Fig. 16. Turbo ventilating fan, type TV, with housing (with signal device).

for driving, the voltage and type of supply.

3) The volume (air or gas) required per unit of time. The specific weight, temperature, *etc.* if these should depart from ordinary conditions.

4) (a) *For fans with pipe lines.*

The *static pressure* or *total pressure* and delivery and intake duct dimensions (diameter) at points near to the fan, where the specified pressure must exist and also the space at disposal, should the fans be provided with connecting pieces. Particulars should also be given as to whether static pressure or total pressure is to be assumed.

(b) *For fans without pipe lines.*

The static pressure equals the static pressure difference as described above. When the quantity of air is to be delivered with free inlet and outlet, *i.e.* if the static pressure≈0, this should also be stated. In cases where the fan may work with variable pressure and different deliveries, this should always be stated, as fans, with the exception of Schlotter ventilators and certain types of propeller ventilators, require a greater amount of power when delivering large volumes of air than with lower quantities even at the same speed, which can, in turn, exercise some influence on the choice of a suitable size of motor.

In the case of fans for special purposes as forge and cupola blowers, organ blowers, *etc.* it is often difficult for the customer himself to specify the desired capacity, pressure, *etc.* and the manufacturer must often be satisfied with particulars regarding a few of the conditions only, such as information regarding the number of forges, their diameter, *etc.* The particulars which are required in the case of fans for special purposes are commonly obtained from catalogues and question sheets issued by the various makers.

It is very important that the particulars given in catalogues and descriptive booklets should be as complete as possible, so that they will be of assistance in the selection of suitable fans in different cases. If the quantity of air and pressure is given, it follows from what we have said as regards fans for connection to pipe lines, that the inlet and outlet dimensions should be given.

The present article is only intended to enumerate the technical details which are necessary for fans in general, where demands, as regards capacity, necessary h.p. and suitability for any particular service, are relatively high. The particulars we have given may well be of interest to all engineers having to deal with fans, as showing the most important of the technical particulars, which have been found necessary by Asea and which have been followed out when supplying fans.

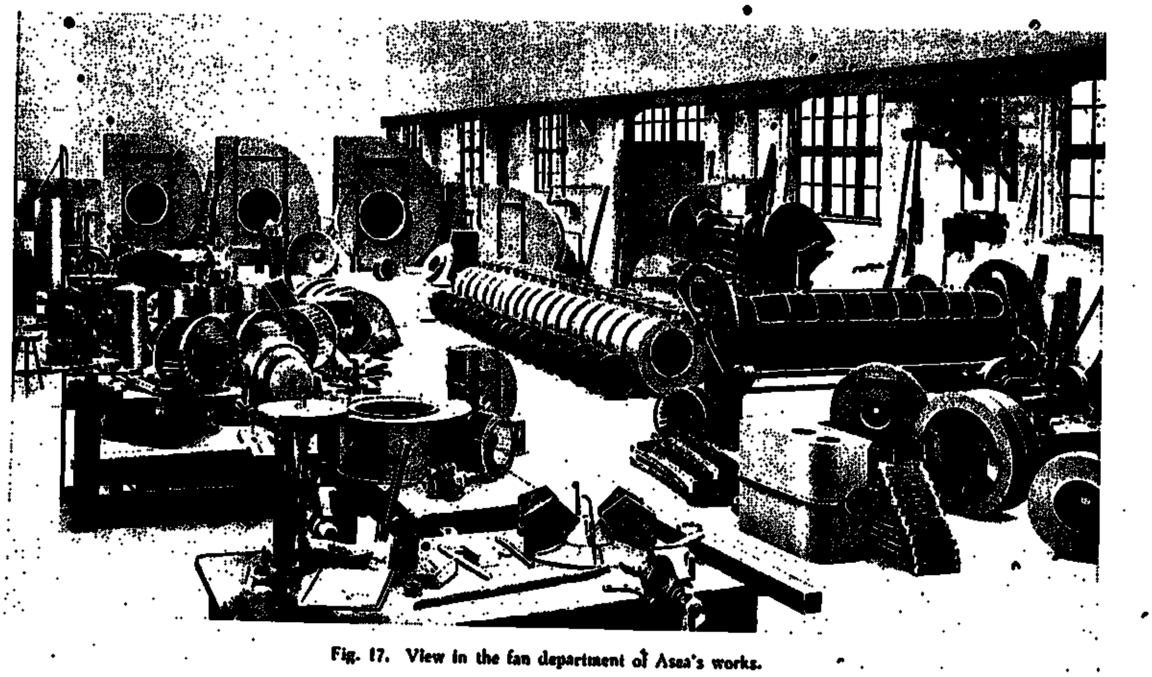


Fig. 17. View in the fan department of Asea's works.

ELECTRIC TRAMCARS FOR ALSACE LORRAINE.

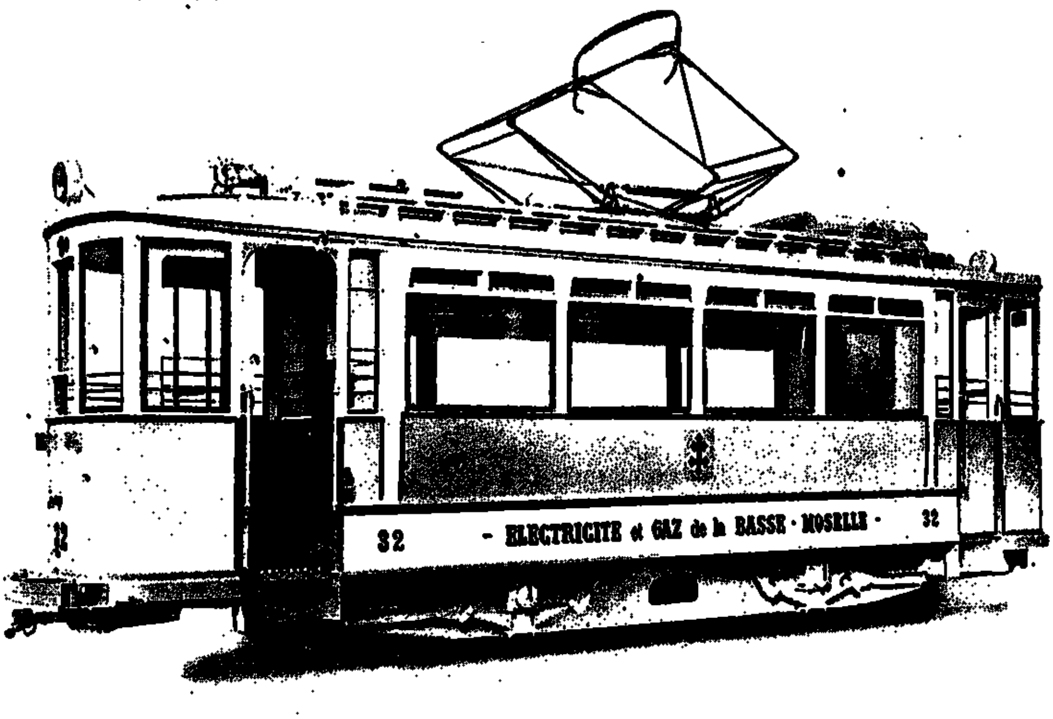


Fig. 1. Exterior of tramcar.

Fig. 1 above is an exterior view of one of the tramcars furnished with electric equipment of Asea's manufacture which has been in service for about a year on the 23 km suburban line known as the Vallée de Fontoy in Alsace Lorraine. The electrical equipment was supplied by Asea and the train constructed in cooperation with the builders of the bodies, Messrs. de Dietrich & Co. of Reichshoffen, who supplied the whole of the mechanical parts. It is interesting to know that this important firm is one of the oldest industrial plants in France and is belonging since about 280 years to the family of Messrs de Dietrich.

Each tram is provided with two motors designed for an output of 65 h.p. at 730 r.p.m. for a line voltage of 650. The gauge is 1,000 mm and the diameter of the wheels 820 mm.

The equipment is of the Asea standard for small tramcars designed for 500—700 volts D.C. These equipments during the last few years have undergone considerable alterations in design and a detailed description may accordingly be of some interest.

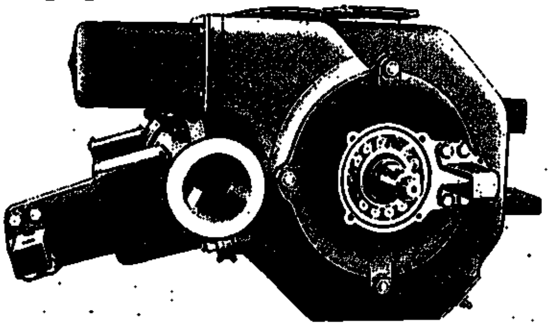


Fig. 2. Traction motor type LJ 56, 114 h.p., 550 r.p.m. with roller bearings.

The motors are of the modern self-ventilated type furnished with roller bearings for the armature shaft. The motor construction will be clear from figs. 2 and 3, the latter illustration showing the completely erected motor.

The field magnet frame is not split and this is becoming general practice in the case of ventilated motors. Earlier motors for tramway service were in general split horizontally as this was regarded as an advantage from the maintenance standpoint, making the machine accessible for overhauling and inspection by dismantling the lower half of the frame over a pit.

From a practical point of view this advantage is, however, not of such great importance as most of the work to be carried out can be effected more quickly and better if the motor is first removed from the car and afterwards dismantled. As regards construction the undivided field has the advantage that the poles can be placed in the most suitable positions and a more satisfactory utilisation of the limited space available is made possible. At the same time, the undivided field

has better magnetic characteristics, and manufacture is more simple and easier to carry out. In a ventilated motor a relatively high vacuum may exist in the machine at high speeds and with a divided field frame it is easy for oil and dirt to be drawn in, and this fact contributed considerably to the general adoption of undivided field when the self-ventilated motor was introduced.

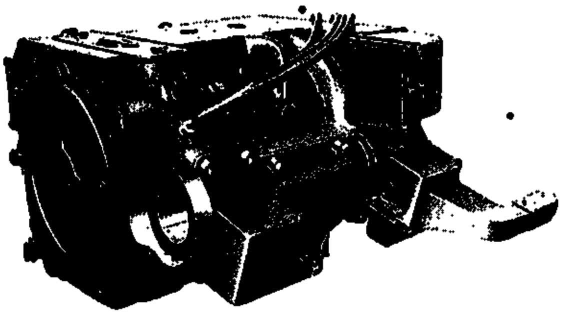


Fig. 3. Completed traction motor.

Ventilation is carried out by a fan wheel mounted on the motor shaft, which draws air through a filter on the reduction gear side arranged with an air intake at right angles to the length of the car. The cooling air passes through the motor in two parallel paths, partly through ventilating ducts in the rotor and partly through the openings between the field coils and is then discharged by the fan through an outlet at the commutator end. The filter is provided so that the heavier dust is separated from the air and it is so arranged as to be easily removable for cleaning. As both field and armature windings are, on account of their construction, practically speaking unaffected by damp and dust, the construction of filter adopted provides, in most cases, a fully sufficient amount of protection. In cases where the line is laid in particularly dusty roads, the air intake may suitably be connected with the interior of the car, through a flexible pipe.

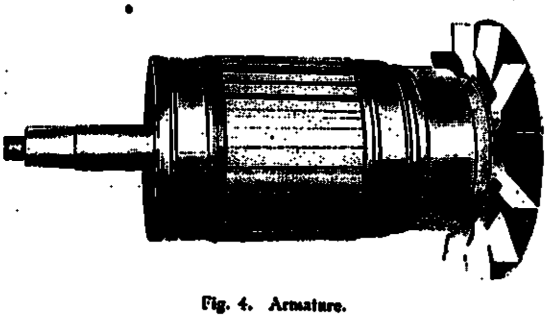


Fig. 4. Armature.

The field magnet of the motor is of Siemens Martin steel and is arranged with large openings for inspection which are covered with dust tight removable covers. The shaft is of nickel steel with carefully ground bearing journals and can be removed without completely dismantling the armature.

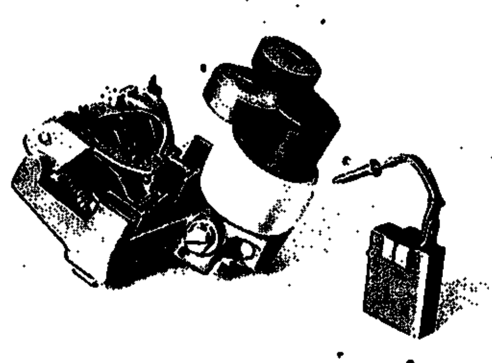


Fig. 5. Brush holder and brush with conducting tail.

The roller bearings for the motor shaft are amply dimensioned and are mounted in roomy and well enclosed housings. The driving wheel shaft bearings are split sleeve bearings and are arranged with pad lubrication.

The rotor copper is cotton insulated and the coils are insulated from iron by means of mica and are laid in open slots where they are retained by fibre keys and bands of steel wire. Larger motors of the same type have the rotor windings insulated throughout with mica. When the winding is completed the armature is va-

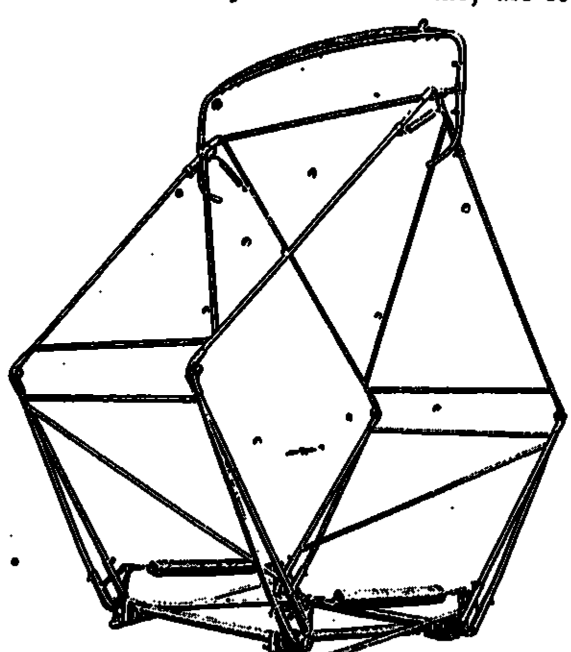


Fig. 6. Pantograph collector.

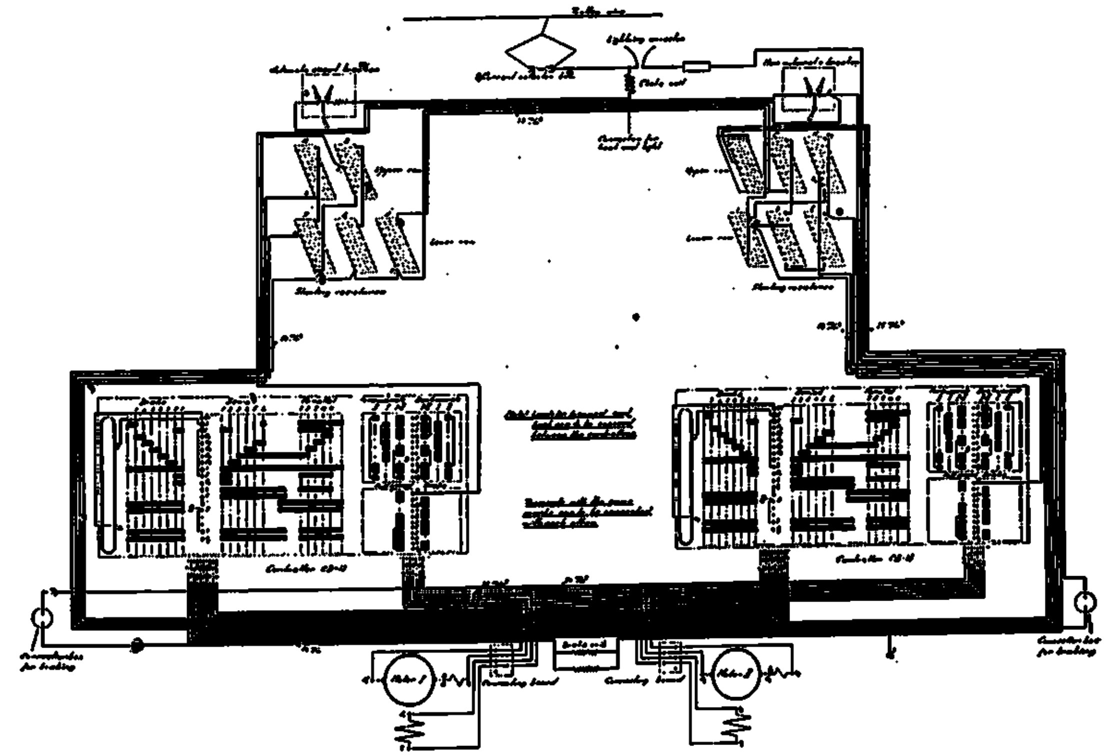


Fig. 7. Diagram of connections.

cuum impregnated after which the coil ends are covered with cloth hoods, impregnated with a special varnish. The windings are in this way practically completely protected against damp and dirt.

The commutator, which is made with segments of hard drawn copper, insulated with micanite, has a wearing depth of between 10 and 20 mm without the mechanical or electrical properties being in any way effected. After the wire bands have been put in place, the armature is tested at an overspeed of 50% above the highest speed likely to occur in use, and subjected to careful static and dynamic balancing. Fig. 4 shows a completely finished armature.

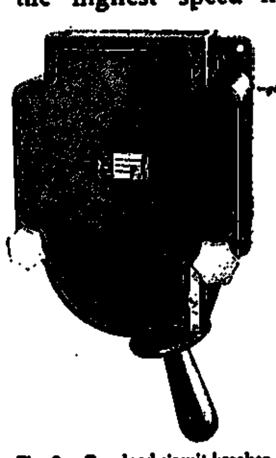


Fig. 8. Overload circuit breaker type AM 200.

The field winding consists of four main and four interpole coils and these are impregnated with a heat resisting compound under a high pressure so that a higly compact winding having the greatest possible properties of resistance to dust and damp is obtained, while the coils are also well able to withstand high temperatures.

The brush holders are of bronze and are fitted in an adjustable manner on insulated bolts which are mounted in supporting brackets, using mica insulation and porcelain insulators. The brushes are furnished with interchangeable contact clips having tails rivetted to them. The arrangement of the brush holders with brushes and tails can be seen in fig. 5.

The toothed ring of the main gear wheel is of Siemens Martin steel with a tensile strength of about 55 kg/mm^2 and the pinion is of specially case hardened carbon steel with a tensile strength of about 80 kg/mm^2. The teeth are cut in special modern machinery. The gear casing is of sheet steel with oil bath lubrication. The current collector, having regard to the high maximum speeds, reaching approximately 40 km/hr, has been designed of the pantograph pattern with an automatically adjusting sprung bow.

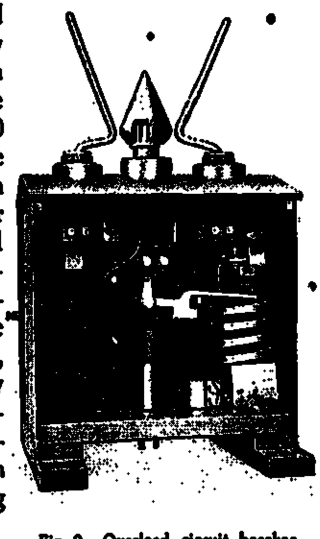


Fig. 9. Overload circuit breaker type ABM 1.

The connecting up of

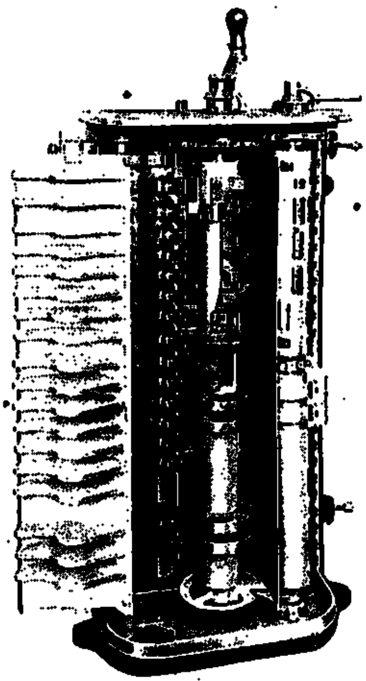


Fig. 10. Controller.

the electrical equipment is shown in the diagram, fig. 7.

From the pantograph collector the current is led to a reactance coil mounted on the roof of the car, one pole of which is coupled up to a lightning arrester of the horngap type and from there through two circuit breakers in series to the controller, resistance and motors. The circuit breakers are of standard tramcar pattern conveniently placed for hand operation from the driver's position. One of these circuit breakers is provided with adjustable overload release. These circuit breakers have particularly heavy contacts and powerful magnetic blow-out, as shown in fig. 8. Fig. 9 shows an overload circuit breaker of a different type intended for a somewhat heavier breaking capacity.

The construction of the controller is illustrated in fig. 10.

In order to keep down the overall height of the controller and, at the same time, to allow the use of fairly wide fingers on the main controller drum, some of the group connections made when changing over from running to braking are furnished on a separate drum, the contacts of which only close when carrying no current. Changing connections for reversing the direction of rotation is effected on a special reversing drum and the contactors of this also only close when carrying no current.

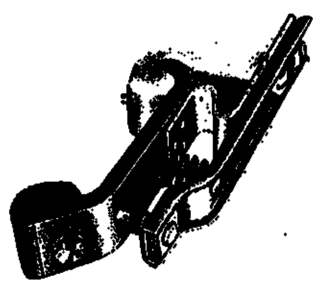


Fig. 11. Contact finger.

The main drum is furnished with six running positions with the motors in series, five positions with the motors in parallel and seven positions for short circuiting the motors to provide braking effect. When required, one of the series positions and up to two of the parallel positions can be used for shunting the field of the motors.

The main controller drum consists of a heavy cylinder of insulating material with an asbestos protective covering. The sector supports are of brass and the contact segments themselves are of hard drawn copper.

The contact fingers of the main drum are of strong adjustable channel type and have spiral springs and interchangeable copper contact pieces as shown in fig. 11. This design of finger has the advantage, not possessed by laminated fingers, that welding up under the action of the arcs is eliminated.

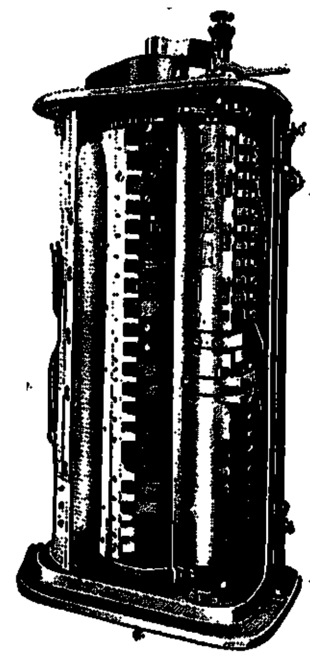


Fig. 12. Controller provided with dead man's handle.

The fingers for run and brake control and for the reversing drum which do not operate when carrying load have heavy laminated springs of phosphor bronze. The main drum and the reversing drum can only be moved when the main drum is in the "off" position. The running and braking drum is operated by a cam from the main drum in such a way that when the main drum is placed in the first position for running or braking it is turned into the corresponding operating position and remains there as long as operation continues on the same part of the main drum. When the main drum is returned to the "off" position the run and

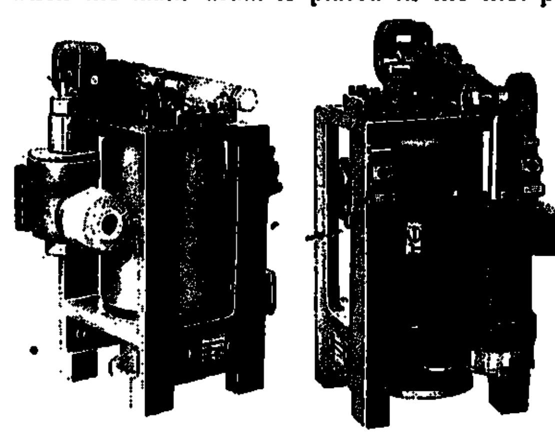


Fig. 13. Automatic emergency brake valve.

brake drum is also returned to the neutral. In this position all the circuits made on the main drum are open.

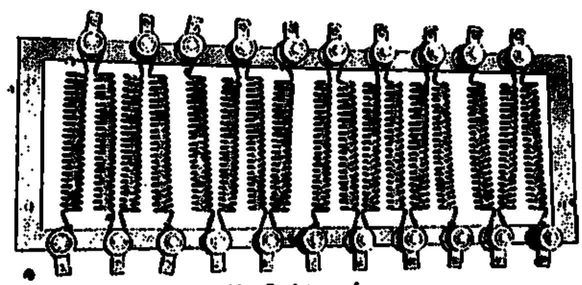


Fig. 14. Resistance frame.

The electro-magnetic blow-out on the main drum is particularly strong and this has been arranged while keeping the blowout coil of reasonable dimensions by arranging for it to be short circuited when the controller is in the highest speed position and only connected in circuit during starting and braking periods.

When the "pay as you enter" system is used, the controller is provided with a dead man's handle in connection with the main controller drum. When a spring button is released, a relay on the motor circuit is automatically broken and the air brake is applied after a certain adjustable time lag, if the driver does not depress the stop button again. Fig. 12 shows a controller fitted with a dead man's handle and fig. 13 the automatic emergency brake valve which was used on a number of the earlier cars supplied by Asea.

The starting and braking resistances are made up of constantin wire spirals mounted in 10 frames which are placed under hoods on the roof of the car. The resistance spirals are supported on the frames from insulators and are provided with connecting screws by which adjustment of the intervals of the resistance can be easily effected. The design is shown by fig. 14. In addition to these resistances a further resistance frame is provided, suitably designed for working in conjunction with the electro magnetic track brakes on the motorcar and trailer cars. The connections for these track brakes can be seen on the diagram, fig. 7.

THE FIRST ASEA DYNAMO.

We have just been successful in securing the return, for inclusion in the Asea Museum, of the first electrical machine constructed by Jonas Wenström, the first technical Director of the Company, and which was manufactured by the Electrical Company of Stockholm — now Asea. At the same time, we were able to obtain the Wenstrom magnetic ore separater, for the excitation of which the dynamo has been used. The dynamo in question may be regarded as a valuable curio from the electro technical point of view and it will, no doubt, interest a number of the readers of the Asea Journal to have an opportunity of examining the particulars, together with some illustrations and notes, touching the construction and characteristics.

As far as we have been able to ascertain Jonas Wenstrom had previously had only one machine built, namely the dynamo type A which was completed in February, 1882, at Orebro but this was scrapped many years ago. The drawings for the dynamo now in question, type B No. 1 (which is thus actually the second machine built to Wenstrom's design) were completed in September 1882 and the machine was manufactured along with five similar dynamos during the remainder of that year, and in the year following.

The dynamo, the general construction and appearance of which can be gathered from the photographs and drawings, was 2-pole with concave depressions at the poles, a feature which gained it the nickname of "Stew-pot". (The first dynamo of type A referred to above was, on account of its low height and general appearance, known as "The Tortoise"). On examining the drawings the large pole arc will be immediately apparent and it is particularly worthy of note that the edges of the poles are inclined by an amount which approximates to the slot spacing. The armature is of ring type with a brass spider and has semi-open slots for the winding, which consists of 8 (or 10) turns of 2 mm copper wire in each of the 42 slots.

In developing the design it is obvious that the chief endeavour has been to obtain a short and easy path for the magnetic flux and to restrain this to the greatest possible extent so as to prevent magnetic leakage. With reference to this point and the means taken with regard to it is interesting to read some of the remarks made by Jonas Wenstrom in an article written in 1885 regarding his system of dynamo design published in La Lumière Electrique.

"The main idea in my system of dynamo construction is to make better use than is commonly done of the magnetism developed by the field current and thereby, other things being equal, to reduce either the speed of the dynamo, its internal losses or else the amount of active material employed. The method by which this idea has been put into practice provides other

advantages also, such as simplicity of manufacture, protection against external influence and good magnetic connection between the poles and armature, together with a good rigid construction and lastly from the commerical stand point an arrangement which, as regards appearance and design, marks a considerable departure from other dynamo systems.

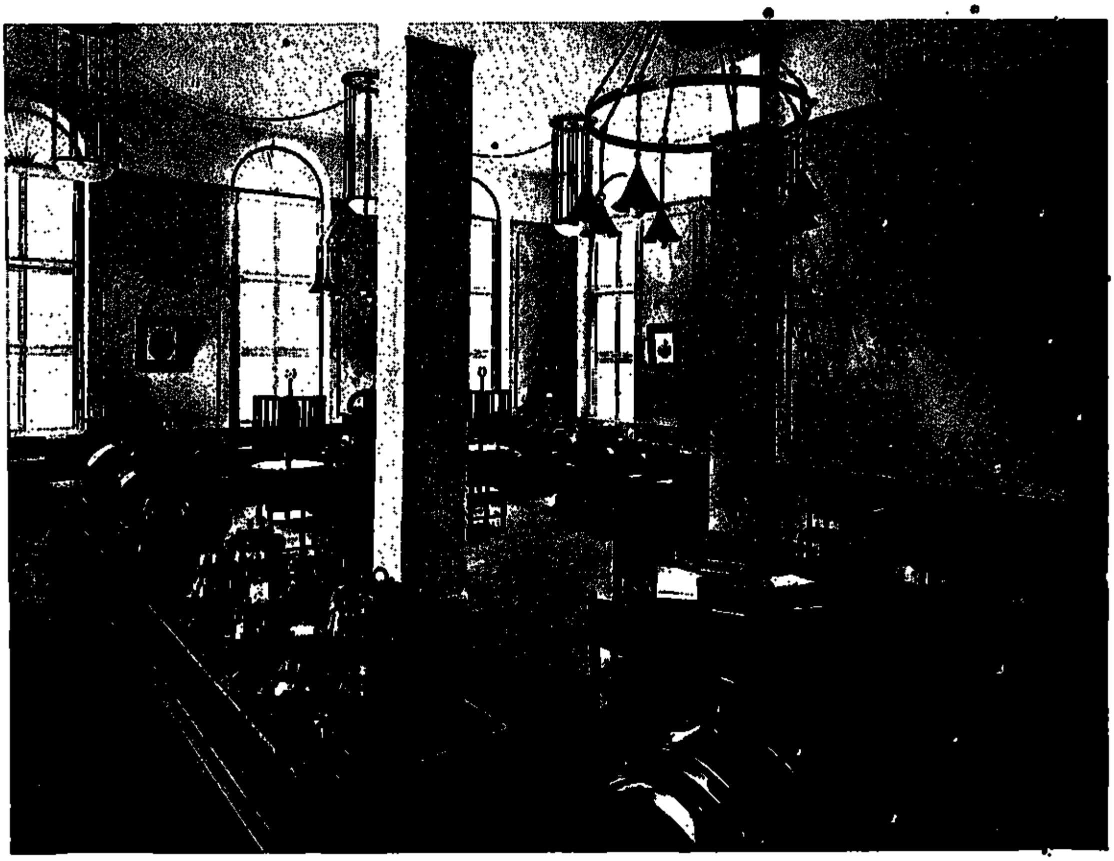


Fig. 1. Asea's museum.

Starting from first principles it is known that an electric current flowing in a conductor creates a magnetic field at all points surrounding the conductor. In ordinary dynamos where the field magnets consist of iron cores surrounded by windings, only a part of the magnetism, that which is produced where the iron core is situated, is collected, conducted to the poles and utilised. The remainder, about half of the total, is dissipated in the surroundings where it often makes its presence known *e.g.* by magnetising watches *etc.*

In my dynamo, the field winding is enclosed on all sides by iron which completely absorbs the magnetism produced and only to an inconsiderable extent can it be detected outside the machine. The iron core must have sufficient thickness to carry the whole flux and in addition it must be designed so as to have equally good magnetic conducting properties throughout, so that at no part will the flux take some other path outside the iron core and on the other hand, the core will not be unnecessarily thick anywhere. On the drawings where the magnet yoke A is joined to the poles N and S fixed upon plates B and cylinders C, it will be noticed how the proportioning is arranged and it will be seen also that unavoidable joints are placed in such positions where they can be made large and broad so as to reduce the reluctance which a break in the iron core introduces into the path of the magnetic flux.

After having made arrangements for the protection of magnetism and its conduction to the poles in the above manner, so as to give rise to as little loss as possible, it remained to reduce opposition to its passage from pole to pole through the armature. This is the more important as it is in the armature only that the magnetism is made used of and it should accordingly be conducted there with as little loss as possible. The resistance to the flux is caused here by the break in the iron circuit which is

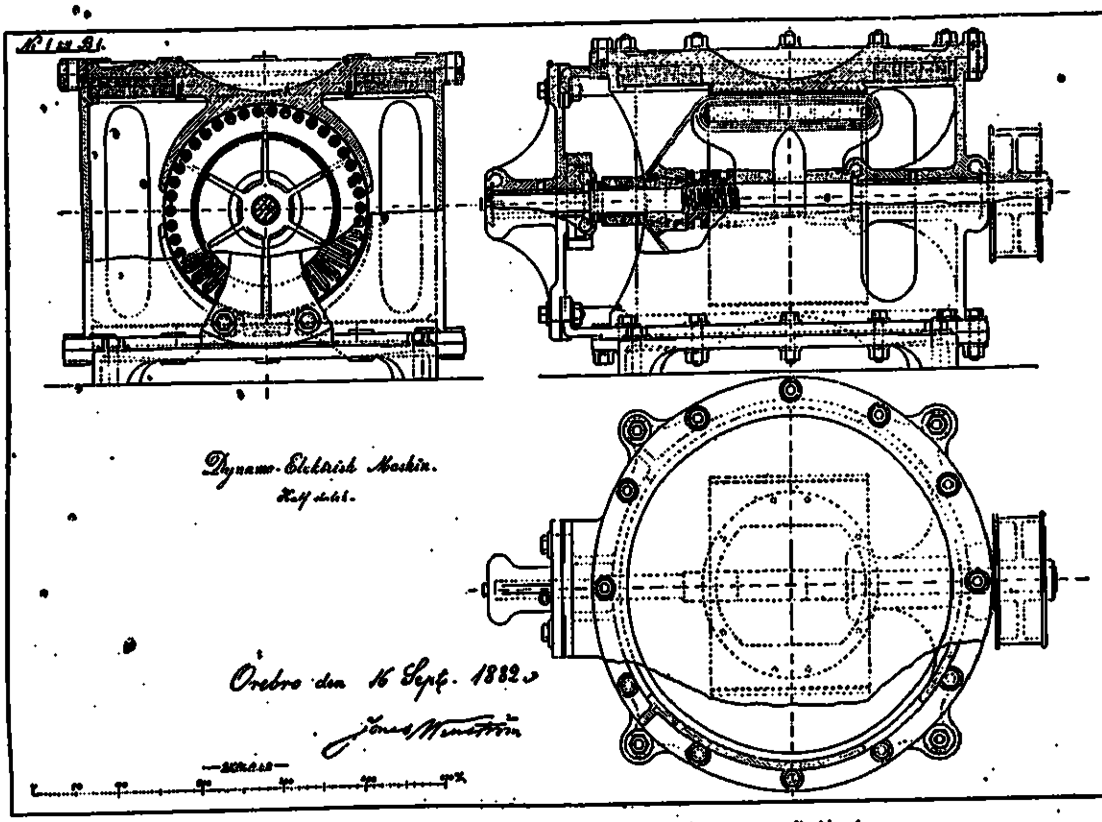


Fig. 2. Facsimile of general arrangement drawing for dynamo type B, No. 1.

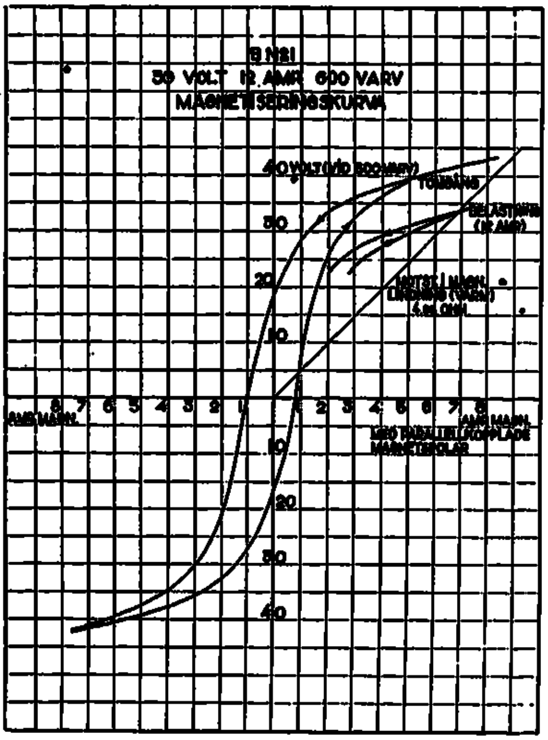
often considerable due to the distance between the poles and the iron core of the armature. To ensure free rotation of the armature in all cases, more or less clearance is essential but this is often increased by placing the armature conductors on the outside between the poles and the iron core.

In my dynamos this disadvantage has been reducted to a great degree by sinking the conductors into the armature core in cylindrical slots provided with small openings to allow the wire to be placed in position. In this manner the iron core has a series of projections which enable an unusually large iron surface to be presented in the neighbourhood of the poles and at the same time the armature conductors are covered and protected so that it is possible to reduce the air gap safely to a much smaller value than is usually the case. The size of the armature surface and also the armature core in general, which has to be traversed by the same flux, is carefully designed so that it affords sufficient cross sectional area at every point to carry the whole of the magnetism passing. Accordingly, in this armature no flux passes through the conductors themselves, so that it does not matter whereabouts in a slot a wire may lie and it can be at the bottom or at the top equally well. The iron surrounding the conductors also serves to shield magnetically the conductors in one slot against induction from conductors in neighbouring slots. The self-induction of the armature is thereby reduced.

How completely such an armature can collect the magnetism from the poles can easily be shown as if an armature is withdrawn from one of my dynamos it is possible to detect a considerable amount of remanant magnetism in the poles which cannot be observed when the armature is replaced.

I have indicated here how by my dynamo system the greatest possible saving in magnetism has been effected, and as magnetism for its production requires a certain expenditure of work it is clear that I have also succeeded in effecting a saving in energy which, if desired, can be exchanged against a reduction in speed or in material. In most cases for practical reasons, it is desired to reduce speed to a minimum and to put this requirement before any saving in power or material."

In striving to reach the end mentioned above a number of other important conditions were disregarded but this is quite natural, taking into account the general point of view which prevailed at the time with regard to this special



B N:o 1 = B No. 1. 30 volt, 12 amp., 600 varv = 30 volts, 12 amps, 600 r.p.m. Magnetiseringskurva = Magnetisation curves. 40 volt (vid 600 varv) = 40 volts (at 600 r.p.m.). Tomgång = No load. Belastning (12 amp.) = Load (12 amps.) Motst. i magn.-lindning (varm) 4.91 ohm = Resistance of field winding (hot) 4.91 ohms. Amp. magn. = Magnetising amps. Med parallellkopplade magnetspolar = With parallel connected field coils.

Fig. 3. Characteristic curves for dynamo type B, No. 1.

phase of design and the theoretical and experimental results available. If the external leakage was small there still remained a very considerable amount of internal leakage between the pole shoes and the surrounding parts of the magnetic circuit. It is, however, indisputable that the placing of the armature winding in more or less open slots was a real piece of pioneer work as it enabled the armature windings to be made an excellent mechanical job and at the same time reduced the magnetic reluctance in the air gap and this was found of the greatest possible importance also in the case of induction motors. As regards D.C. machines the endeavours which were made, more or less successfully, to reduce the magneto motive force in the air gap were anything but favourable to electro magnetic stability in general and to commutation in particular. The small part played by the air gap in the magnetic circuit can be noted from the no load magnetisation curve, fig. 3.

The dynamo was originally designed for an output of 60 volts and 25 (to 30) amps. at a speed of 1,200 r.p.m. As it did not run very successfully on this load the output was afterwards reduced to 30 volts and 12 amps. at 600 r.p.m. without any other alteration than connecting the two shunt field coils in parallel and increasing the air gap from 1 to 2 mm. On this load the machine has operated during its whole working life and the results as regards heating reliability and wear, having regard to the conditions in general, must be regarded as being entirely satisfactory.

Tests have now been made to determine the efficiency on the above load with the following results:

Bearing and brush friction	80 watts approx.
Hysteresis and eddycurrent losses ...	22 »
Resistance losses in armature winding and brushes	65 »
Resistance losses in field winding and rheostat	150 »
Output at terminals	360 »
Total	677 watts

From which accordingly the efficiency

$$\frac{360 \cdot 100}{677} = 53\,\%$$

This value having regard to the reduced output and the low speed must be regarded as being relatively high. It is clear that the output (current) was not reduced to the great extent mentioned on account of heating, as it was found that the temperature rise with this load was not more than approximately 30°C.

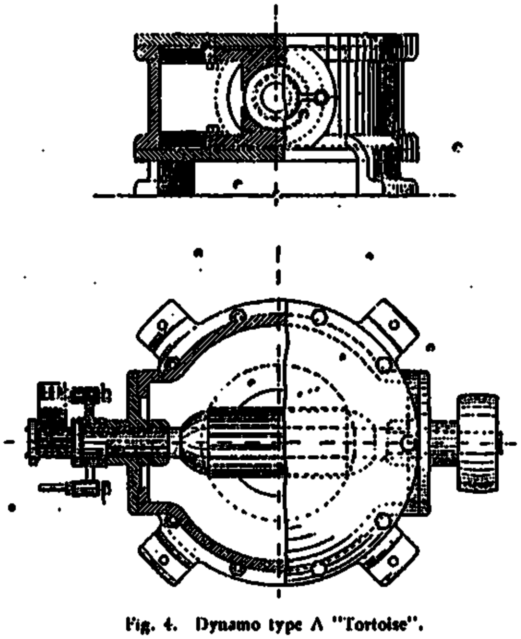


Fig. 4. Dynamo type A "Tortoise".

The fact that it was not possible to obtain a good (sparkless) operation of the machine at the original output for which it was designed (60 volts, 25 amps., 1,200 r.p.m.) was due among other things to the ampere turns of armature reaction being not less than 10 times as great as the ampere turns for the normal flux through the air gap (1 mm). The necessary leading forward of the brushes from their normal position so that the coil under commutation was under the leading pole face caused an induced *e. m. f.* of some tens of volts to be generated therein on account of the armature reaction, due to the high magnetic induction in the short circuited coil. That this must have resulted, to say the least, in an "irreproachable amount of sparking"*) at the brushes is quite clear.

*) This was the expression used on the test report of one of the older machines.

In spite of the troubles we have touched upon above (which were also to some extent found in older designs and which he sought to overcome by the use of commutating poles, earlier than 1890, although this idea was not proceeded with, due to causes for which we have no room to explain fully here), Jonas Wenstrom's old dynamo machines when viewed in their proper historical surroundings must be looked upon as first class and worthy of taking their place among the best which were produced at that time. The most noteworthy point about Jonas Wenstrom's dynamo was the rigid and natural connection between the electro magnetic and mechanical parts which were united to a constructional and organic whole — a quality which was very often lacking in other machines produced at that time, when electrical technology was quite in its infancy.

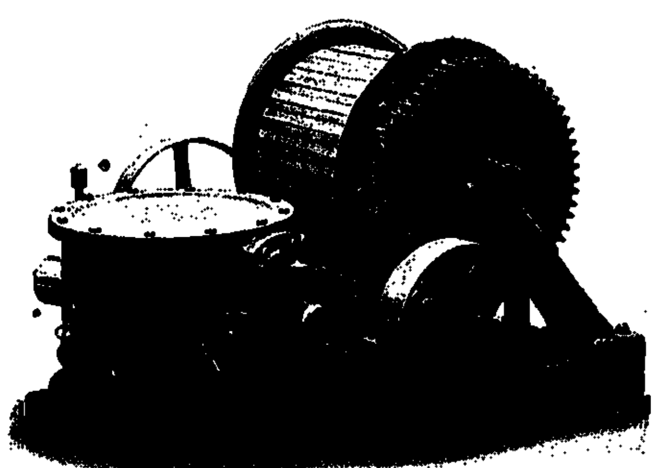
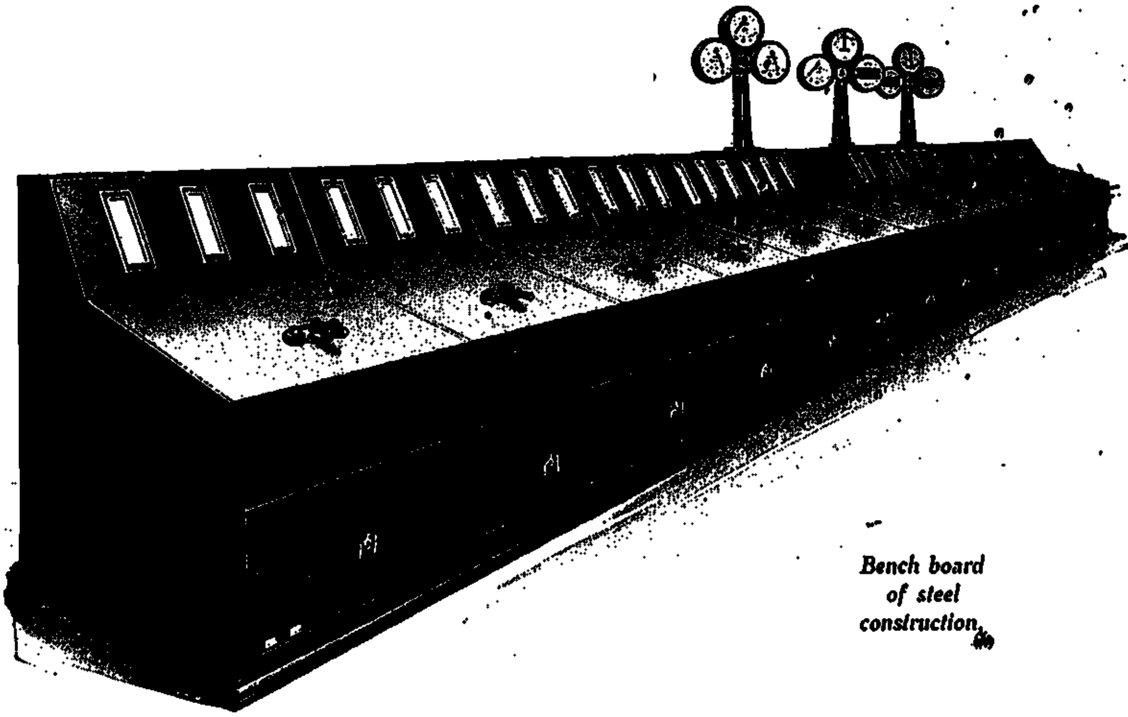


Fig. 5. Dynamo type B, No. 1, with Wenstrom magnetic separater which it excited for about 35 years.



Bench board of steel construction.

SWITCHGEAR

Even where the best electrical machines are employed good operating results, free from disturbance, can be obtained only if the necessary apparatus for controlling, regulating and protecting the machines is constructed in a manner designed to meet the working conditions fully.

This applies in equal degree to combinations of instruments and apparatus which are grouped under the general heading "Switchgear" and where reliability and suitable arrangement of the different pieces of apparatus in relation to one another is of the greatest possible importance.

Experience extending over many years in this direction is a gurantee that Asea's designs to meet any conditions are always the most suitable and that the construction, material and workmanship are of the highest possible class.

As in the case of all Asea manufactures, no piece of apparatus leaves the shops without having undergone stringent tests in both electrical and mechanical respects.

Always apply for our Quotations when in the market for electrical switchgear and apparatus.

ASEA

VESTERAS — SWEDEN

Vesteras 1927, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

ALLMANNA SVENSKA ELEKTRISKA A.B.
VESTERAS — SWEDEN

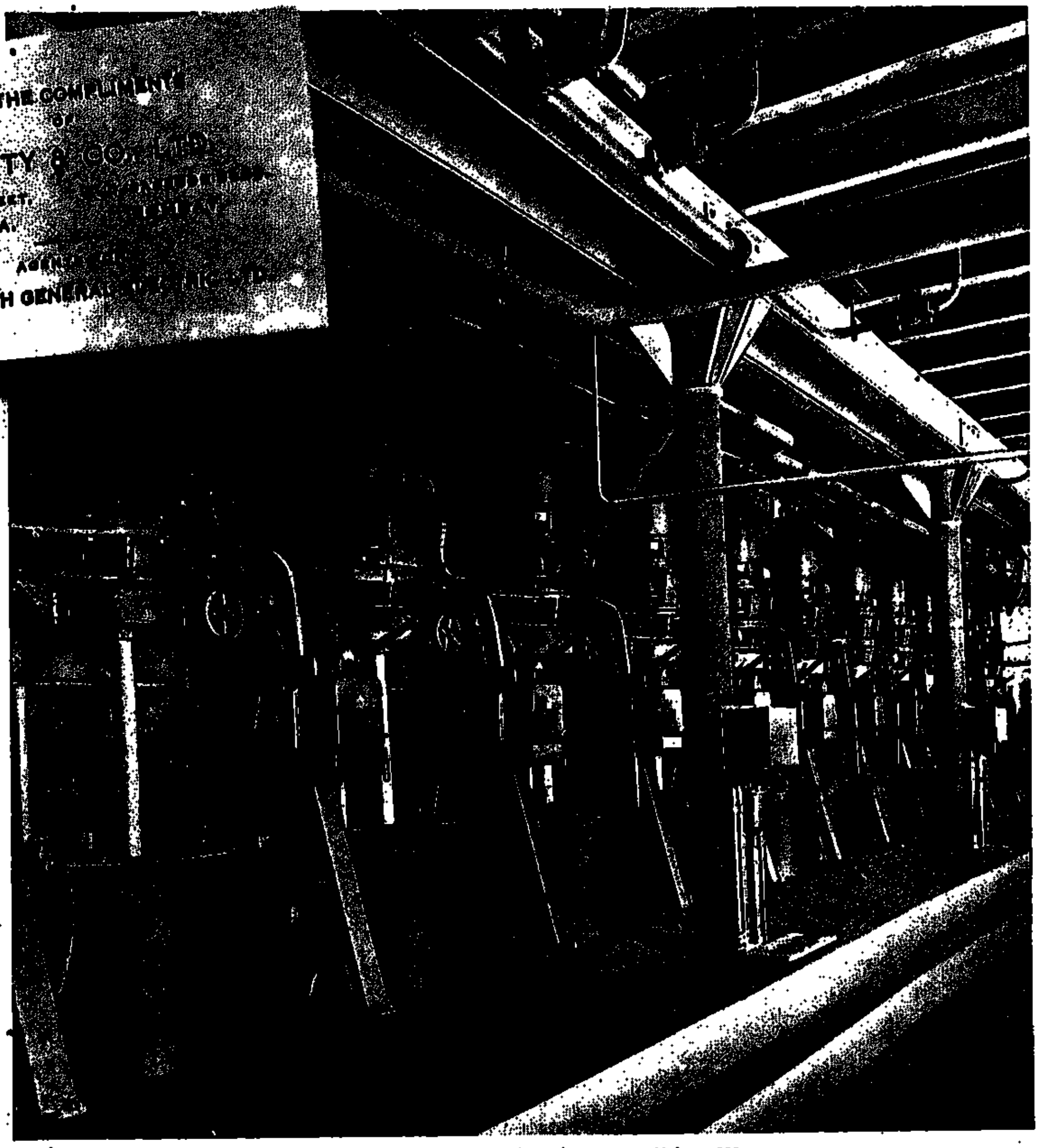
SWEDISH GENERAL ELECTRIC LTD
5. CHANCERY LANE—LONDON

MONTHLY REVIEW

VOL. IV
1927

All correspondence should be addressed to the Editor, Publicity Dept. Asea, Vesteras, Sweden.
Permission is given to reprint articles or extracts from this journal, on condition that the name — Asea-Journal — is clearly stated.

OCT.-NOV.
Nos. 10-11



Sugar centrifuges driven by Asea three-phase motors 20 h.p., 900 r.p.m.

AUTOMATIC STARTERS AND REGULATING DEVICES ON MOTORS FOR INDUSTRIAL SERVICE.

GENERAL CONSIDERATIONS.

The experiences of late years in the difficulty of obtaining skilled workmanship, and the necessity of pushing up production as far as possible while reducing manufacturing costs and loss of time caused by expensive repairs, have aroused increased interest in automatic switchgear equipments with electric machines. Customers have more and more learnt to appreciate the advantages of equipments which can be started by unskilled persons without carelessness resulting in burnt out motors, damaged contacts *etc.* and which allow of simple and easy operation. Thus, in rolling mills the introduction of indirectly operated controllers has made possible rapid reversing operations which, with manual apparatus difficult to handle, were previously impossible. The number of failures has been considerably reduced and to the same extent also repair costs. With printing presses, semi or full automatic equipments have gained a good footing and to run with simpler apparatus would now be unthinkable.

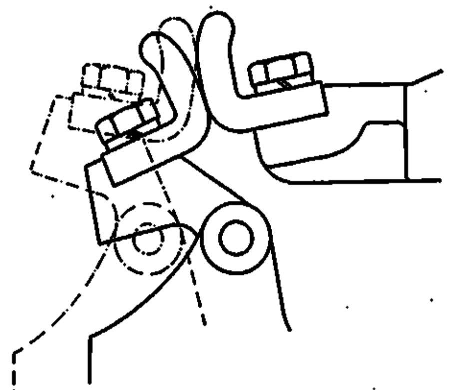


Fig. 1. Sketch showing the motion of the contacts when switching on and off (dotted lines indicate first and full lines the ultimate positions of the moving contact when switching on).

In reviewing the different apparatus equipments for motors, which are used industrially, the following sub-division will be of great help.

1. Hand operated equipments.
2. Indirectly operated equipments.
3. Automatically operated equipments.

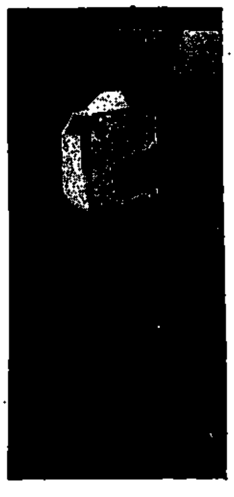


Fig. 2 a. AEI. 1/100 breaking normal current 100 amps, 600 volts D.C.

As characteristics separating these groups the following may be given. With the hand operated arrangement, making and breaking of the motor current and regulation of resistance is done direct by manually operated switches and controllers. With the indirectly operated arrangement, however, these operations are done by the intermediate coupling of an operating current circuit, so that the work is done by a smaller controller or switch (master controller or master switch respectively) which makes the circuit of the current for the coils of the contactor. These in turn effect the making and breaking of the main current. Commonly, in this case an automatic arrangement is moved, which prevents too rapid starting. The attendant can turn the master controller full on but the starter works independently of this so that the current is maintained within safe limits. The last group of starting apparatus is finally entirely automatic *i.e.* it works independently of the attendant. Here we have a separate controlling apparatus which transmits impulses to the starting apparatus, when the motor is to be started or stopped. This opens, or closes respectively, an operating circuit which then in turn acts on the switch in the main circuit. In general, the two last groups of starting apparatus are combined under the name »automatic». In the following also the term "automatic start" has been used in its wider sense. The reasons which lead to a change from the hand operated apparatus normally used to automatic equipment are many. As some of the more important we put forward the following.

1. Operation by controller and regulating panel has limits as with large motor outputs the gear is heavy to operate and in the case of forced drive is not so proof against wear as contactor gear.

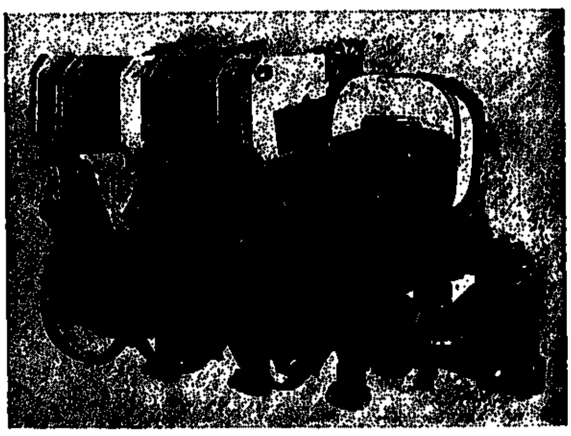


Fig. 2 b. AEV 3/100 breaking normal current 100 amps, 500 volts, 50 periods, A. C.

Fig. 3a. AEV 3/600 breaking 1,300 amps. 600 volts D.C. inductive load.

With hand operated apparatus and intermittent drive it is rare to exceed 60—80 h.p. and if work is very forced we are glad to keep under this.

2. Large powers are broken easier by separate switches than with controllers and regulating panels. With contactors we can also, without greatly increased cost, provide a number of safety arrangements such as no-volt release, overload releases *etc.* With apparatus which is built up of a row of separate elements, such as is the case with a relay starter, it is easier to hold spares or to standardise than *e.g.* with a controller where, by a short circuit, a whole apparatus can easily be damaged while difficulty as regards stocking adequate spares exists on account of the high price.

3. Lastly, there is a line embracing special machines for the drive of which different requirements for regulating, reversing *etc.* exist. Here by automatic arrangements good and economical solutions are often attained.

During the last few years, Asea has made an increasing number of automatic starting arrangements of the following kinds:

1. Printing press equipments of all systems which occur in practice and for the most varied press sizes, from small presses up to the largest double rotary presses.

2. Automatic operating arrangements for sugar centrifuges.

3. Equipments for iron works such as automatic slip resistances for three-phase rolling mill motors, starting and regulating equipments for auxiliary machines for rolling mills such as live rolls, lifting tables, traversing tables *etc.* Equipments for both A.C. and D.C. have been made for the most forced drives which can occur here.

4. Automatic pump and compressor equipments. These have been made both for D.C. and A.C. and for motor sizes from the smallest up to 300 to 600 h.p.

5. Equipments for transport arrangements such as cranes, haulages, winders *etc.*

In the following some of these equipments will be further described in connection with experience gained in planning and running. As an introduction to the descriptions, we shall include a few words on the most important apparatus for automatic drive, namely contactors.

CONTACTORS.

Summary. The importance of contactors in modern automatic motor control gear is emphasised. A description of the general principles and experience obtained is given. Based on this Asea's new series of contactors (solenoid switches) for industrial service has been produced, and by photographs and drawings a review of the types developed is given.

In the newer designs of starting and regulating arrangements contactors have come into increasing use as important auxiliaries. Under the name contactor (solenoid switch) is understood an electrically operated circuit breaker of heavy and simple construction furnished with contacts for air break. They are, as far as possible, constructed for repeated breaking as, *e.g.* for intermittent running. The switches consist chiefly of a contact arrangement and the magnet for its electric operation. As regards construction, the type can be executed in different ways. Like machine types, however, where a standard type of unit has been in course of time conformed to by all manufacturers, there has been a tendency here for a general type to emerge. Accordingly, the main constructional elements and the physical means employed for obtaining rapid break, high breaking capacity, good contact and rapid operation are practically the same for all the more important makes.

This particularly applies to D.C. contactors. As regards A.C. contactors, however, there is a general division in two particular directions. There is a design in which the contactors and operating magnet are on the same shaft and another in which these two elements are connected through links and rods. The former is the more simple and dependable and, from the manufacturing point of view, is cheaper to produce. The latter, however, has certain advantages with respect to space require-

Fig. 3b. AEV 3/200 breaking 600 amps. 600 volts D.C. inductive load.

ments as it can be made more compact and self-contained.

In the following is given a short description of these new breakers. On account of the great use which has been made of them during the last few years and their increasing popularity

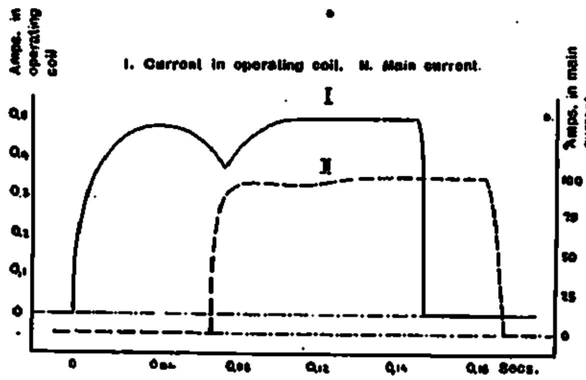


Fig. 4. Oscillogram of current characteristic at contactor type AEL 1/100. Making and breaking.

a general treatment should be of interest. This is all the more the case since it is of importance that the construction of the apparatus and its treatment from the start should be governed by the most complete knowledge.

Contacts.

As destinct from earlier constructions in this direction in which careful fitting of contacts to close limits was of the greatest importance, these switches make use of the so called rolling contacts, the principle of which is shown in simple form in fig. 1. When the contacts first touch, it is at a point considerably nearer the edge than when closing is complete. During the movement between these two points the contacts slide or roll against each other and in this way the surfaces are kept clean and even. In addition the beads of metal and pits which are so easily formed by arcing are confined to a part of the contact where they do not exercise deleterious effect on the current flow. Lastly, such an arrangement has, in comparison with older designs, much greater power to break apart a welding up of the two surfaces by an overload and reliability is thus considerably augmented.

A good contact pressure is of great importance. This is in fact much more important than

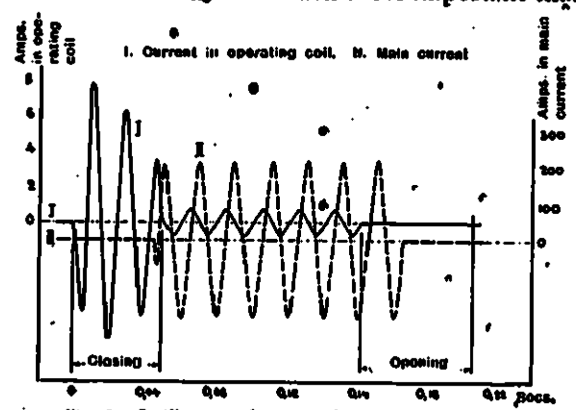


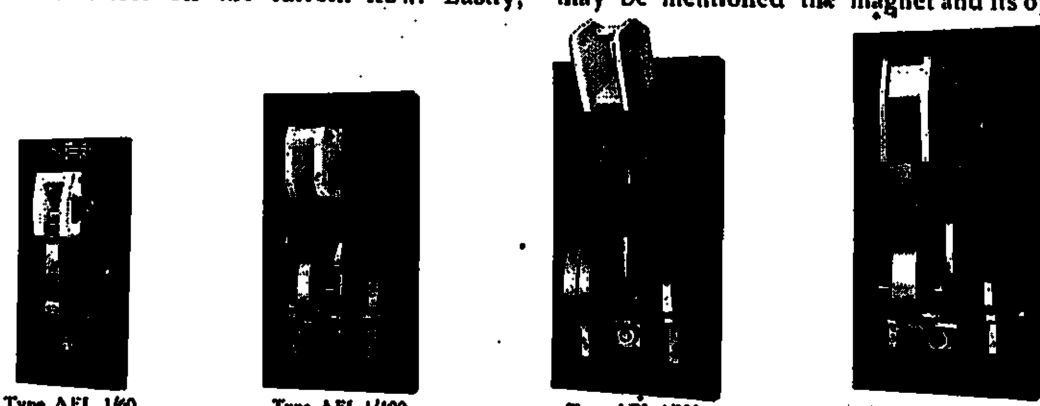
Fig. 5. Oscillogram of current characteristic at contactor type AEL 3/100. Making and breaking.

the utilisation of the contact surfaces (careful grinding in and clean surface).

In order to increase the breaking capacity magnetic blow-out of the arc formed at the contacts has been adopted. The current which is to be broken is led through a blow out coil and caused to generate its own magnetic field. This is so directed that the arc, in an attempt to enclose the greatest possible number of lines of force stretches out until it is too long and breaks. Break in these contactors is particularly rapid. With larger currents it is, however, accompanied by a sharp report and powerful arc. In figs. 2 a and b are seen breaks carried out with normal current. Here the arc is very weak. Figs. 3 a and b show breakers operating at their maximum breaking capacity and a sharp arc then occurs.

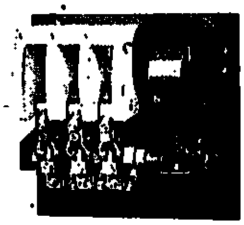
Operating magnet.

As another important constructional detail may be mentioned the magnet and its operating

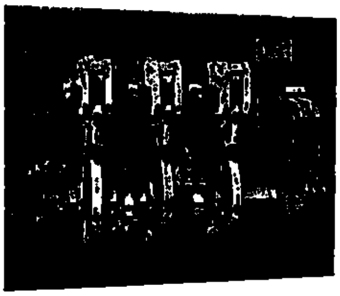


Type AEL 1/60. Type AEL 1/100. Type AEL 1/200. Type AEL 1/350.

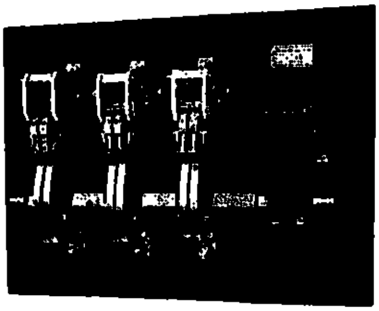
Fig. 6. D.C. Contactors.



Type AEV 3/60.



Type AEV 3/100.



Type AEV 3/200.

Fig. 7. A.C. Contactors.

coil. In general it is now usual to employ operating current of the same kind and voltage as the main current. This applies only up to 500 volts A.C. and 600 volts D.C. The magnets are of a strong and simple construction which

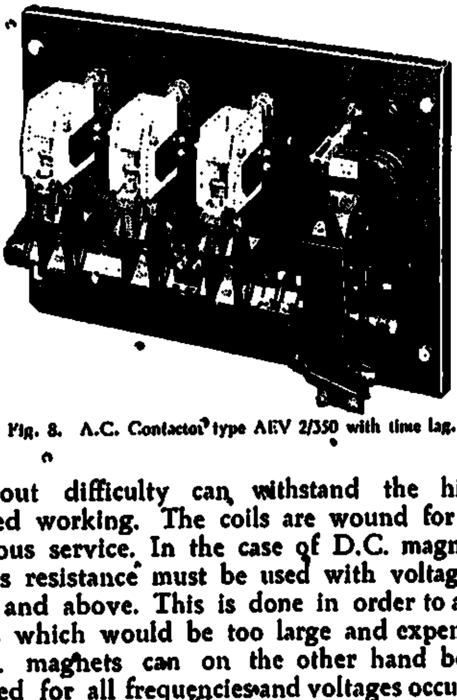


Fig. 8. A.C. Contactor type AEV 2/350 with time lag.

without difficulty can withstand the highly forced working. The coils are wound for continuous service. In the case of D.C. magnets a series resistance must be used with voltages of 110 and above. This is done in order to avoid coils which would be too large and expensive. A.C. magnets can on the other hand be designed for all frequencies and voltages occurring in practice without series resistance.

Some figures regarding closing and breaking speeds can be given. By means of an oscillogram the closing time for a D.C. contactor has been determined as 0.075 secs. and for an A.C. contactor 0.045 secs. while the opening times are 0.040 and 0.065 secs. respectively.

In order to give an illustration of the closing and breaking characteristic curves are given for the new types showing the whole action. Fig. 4 shows these curves for a D.C. contactor and fig. 5 for an A.C. contactor.

It is clearly shown by fig. 5 that the initial current for an A.C. magnet is considerably greater than the current when in the closed position (the maintained current). This is quite natural for all A.C. electro magnets. As, however, the time of closing is so short (1—2 periods) the high starting current has no influence on the supply system or fuses. If operating leads are used having a cross sectional area of *e.g.* 2.5 sq. mm normal fuses for such a conductor can be employed without risk of the closing current causing them to blow.

The closing of our A.C. contactors is accompanied by a loud bang due to the rapid action. This is a normal occurrence with all contactors of similar construction and need not give rise to any uneasiness or to attempts at adjustment. The construction is of such a robust character that such stresses can be easily withstood.

The A.C. electro magnets are carefully faced and fitted so that they do not hum or chatter when they are closed although a faint singing noise exists, as in the case of all A.C. apparatus, arising from vibrations in the iron circuit which is repeatedly demagnetised. This noise is unimportant in most installations. In cases only where such apparatus is used in private houses or must be erected immediately adjacent to living rooms is it disturbing and some means of damping must then be under-

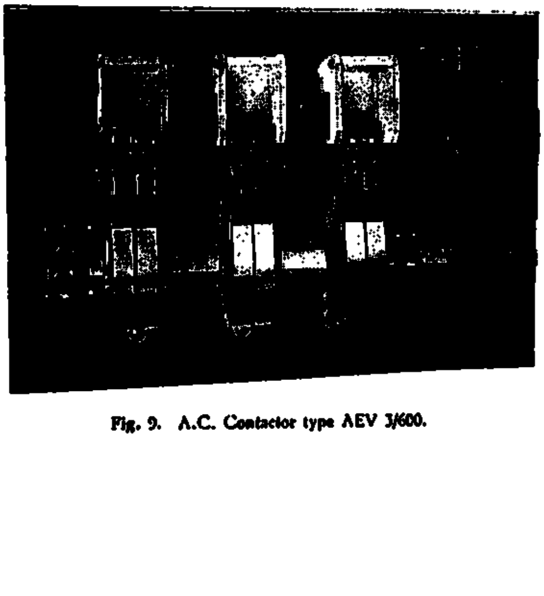


Fig. 9. A.C. Contactor type AEV 3/600.

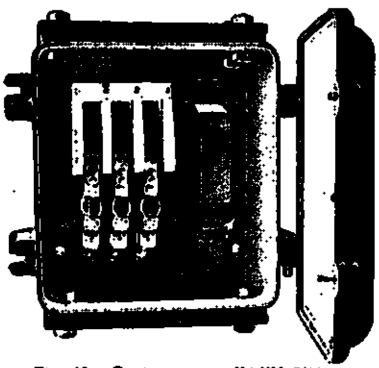


Fig. 10. Contactor type KAEV 3/60, enclosed in dust and drip-proof cast iron case.

taken — as for instance immersion in oil. This also has the effect of greatly reducing the bang on making and breaking circuit.

Forced working conditions.

The general impression given by these contactors is one of a particularly heavy and strong construction. The design has been developed taking account of the heavy wear and great strains to which apparatus is subjected during forced working. Under normal industrial conditions or when used in agricultural developments *etc.* wear is relatively small. It may accordingly be thought that the design is too large and heavy. In addition to the fact that this limits the use of such gear it may be remarked that due to the large amount of material used it is more expensive than necessary. This is, however, not the case to any great extent, as a type which embraces both fields of use can be manufactured on a larger scale and due to standardisation the price can be reduced. A single general type is accordingly justified.

Although contactors for normal industrial service may be regarded as more than amply strong it must be remembered that when they are used for forced work *e.g.* in rolling mills the greatest demands are made upon design and material. A few figures will emphasise this. Normal workshop use may call for *e.g.* only ten starts per day of which five as a maximum follow immediately after one another. Intermittent work in the case of cranes, transporters, winding gears *etc.* may give rise to 20—30 working cycles per hour while in forced working there may be 300 and up to 400 starts made per hour. Here also inching and decking calling for momentary closing may occur and consequently 500 operations per hour may not be too high a value. On a working day this means about 12,000 operations. That such work causes great wear and strains on the different parts is clear. Parts most likely to be worn out are the flexible conductors between the fixed and moving elements, and the contacts. The conductors are subjected to continual vibration and bending and accordingly even if only subjected to low stresses easily break due to fatigue. Tests we have made show that the conductors withstand 50,000 bendings as a minimum, the maximum being some millions. The contactors are subjected to rolling and sliding against each other and to arcs. They should however, be able to withstand several million operations.

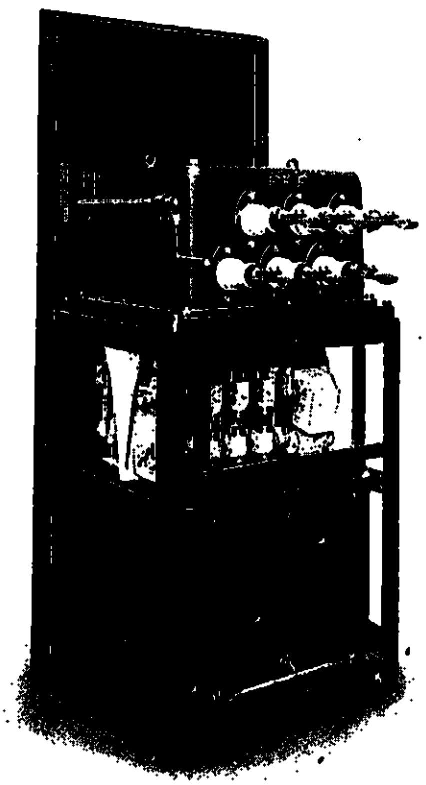


Fig. 12. Oil contactor for forced drive, for reversing a three-phase motor.

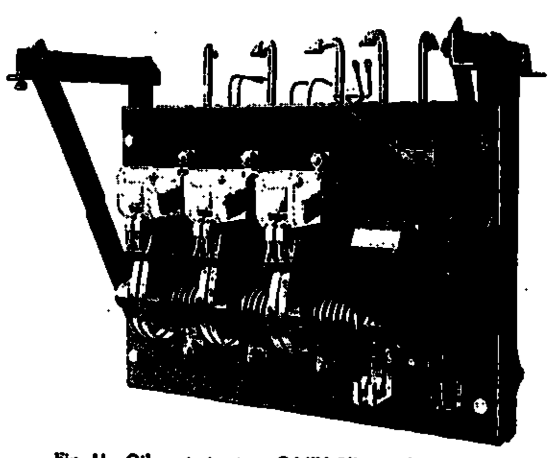


Fig. 11. Oil contactor type OAEV 3/200 without tank.

These two constructional details and also the arcing shields which are gradually eaten away by repeated arcs may accordingly be regarded as parts subject to consumption. A set of spares consisting of connecting conductors, contacts,

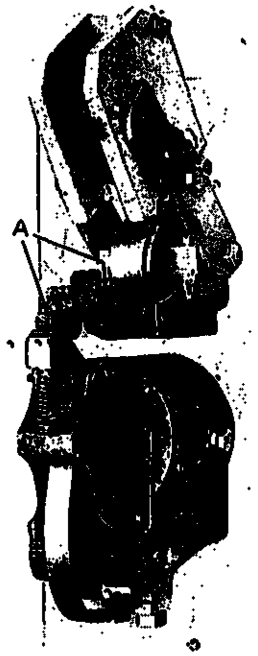


Fig. 13. Arc shield lifted for inspection of contacts. The contacts can be removed by loosening the set screws A.

and arc shields are accordingly necessary on every plant which runs under forced conditions.

Normal current capacity.

As stated earlier these contactors are well adapted to intermittent work. The ability of a contactor to break a certain current is naturally dependent on the number of breaks to be made per hour. The time during which the contactor has actually to carry the current is, however, also of some importance. For a relatively small number of breaks and a short time of use, a smaller contactor can be chosen without risk than for a case where working is forced or the time of use long. In both cases naturally the same working current is assumed. The nominal current carrying capacity for these contactors is accordingly reckoned as the current with which they can operate on work corresponding to normal controller work *i.e.* 30 or at the most 40 operations per hour and with a working time = 1 and time between operations = 3. If these values are exceeded in any respect, the work must be regarded as special and values determined by experience must be used. For example a contactor of this type designed normally for 600 amps. can without difficulty operate on a cycle requiring 200—300 working periods per hour, with approximately 400 amps. average current and 500 volts.

The maximum breaking capacity of the contactor is also of the greatest consequence. By maximum breaking capacity is of course understood the current which the contactor can break once *e.g.* on overload or short circuit when the switch is used as an overload circuit breaker. As general values for maximum breaking capacity it may be stated that a D.C. contactor can without difficulty deal with 2.5 × normal current. For A.C. contactors this value is 4 to 5 × normal. The difference for the two systems is due to their nature. An A.C. always passes through the zero if the breaking time is sufficiently long so that re-establishment of the arc cannot occur and it practically speaking quenches itself. D.C. must, however, be broken at full value and the arc is drawn out and may flash over to neighbouring metal parts.

Contactors types AEV and AEL.

As a standard type of contactor for industrial service Asea employs the pattern with the contacts placed directly over the electro magnet (D.C. type) or on the same shaft as the electro magnet (A.C. type). The contactors are constructed for various nominal current capacities and a series embracing 60, 100, 200, 350 and 600 amps. is standardised. For larger currents designs are now being developed. The maximum voltage is 500 for A.C. and 600 volts for D.C. A.C. contactors can be used for normal current for all frequencies in ordinary use. D.C. contactors are denoted by AEL with a fraction, the denominator of which gives the normal current. Thus AEL 1/350 is a D.C. contactor for 350 amps. A.C. contactors are denoted by AEV with a fraction, the numerator of which gives the number of poles and the denominator the normal current. Thus AEV 3/600 is a 3-pole A.C. contactor for 600 amps.

In figs. 6, 7, 8 and 9 are shown a number of new contactors and these

Fig. 14. Removal of flexible conductor. The lower end of the conductor is unscrewed.

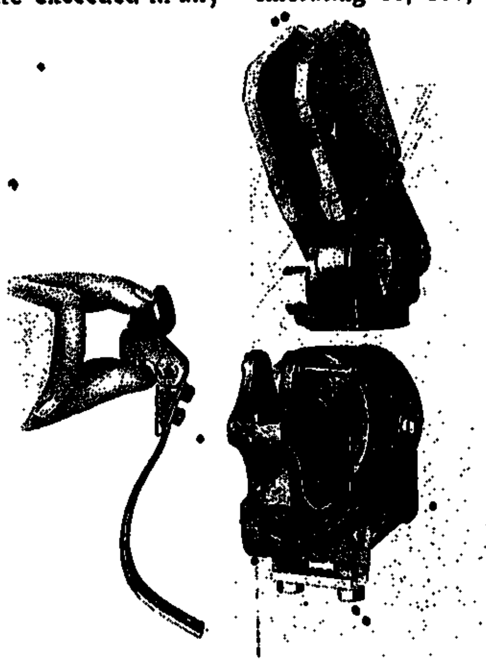


Fig. 15. Removal of flexible conductor. The split pin is taken out and the bolt withdrawn, after which the contactor holder and flexible conductor can be removed.

make clear the most important features of the construction.

The single-pole D.C. contactors type AEL 1/60 and 1/100 for 60 and 100 amps normal current and the single, double, and triple-pole A.C. contactors types AEV 1/60, 2/60 and 3/60 for 60 and 100 amps normal current can also be supplied enclosed in dust and drip-proof cast iron cases. These cases are identical with those used for fuses of sizes II and III in distribution boards of type GSH or for fuses type KSH sizes II and III. For supervision access to the contactor can be obtained through a door locked by special screws.

During the last few years contactors have been constructed for pressures up to 6.6 kV in oil. They can be arranged in a simple manner for electric operation and are always ready for immediate operation as opposed to motor operated oil switches with which there is always a certain loss of time before the closing mechanism has accumulated the necessary energy for operation. In addition oil contactors can be built for forced working conditions, their contacts being relatively insensitive to wear and the presence of impurities. This is naturally brought about at the expense of the breaking capacity which is considerably lower than for a corresponding oil switch. For a motor equipment, however, a breaking capacity exceeding from 4 to 6 times the normal is of no particular advantage. Regular inspection of the oil and contacts is, of course, necessary.

Fig. 8 shows a contactor for air break of the latest construction with damping arrangement to give smooth closing and to prevent damaged contacts. An oil contactor of standard design for a normal current of 200 amps at a maximum pressure of 6,000 volts is shown in fig. 11. Fig. 12 shows a type for forced working conditions for 400 operations per hour.

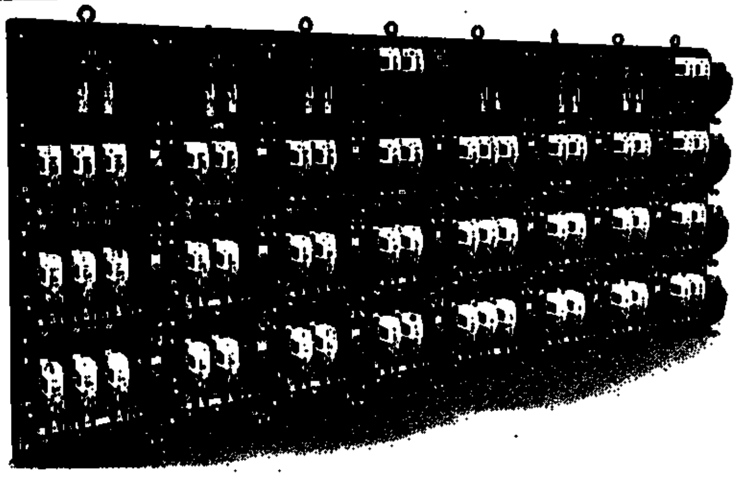
Finally, some photographs are included, figures 13, 14 and 15, to illustrate how the construction allows convenient inspection of contacts and releasing and replacing of the flexible conductor.

AUTOMATING STARTING OF MOTORS.

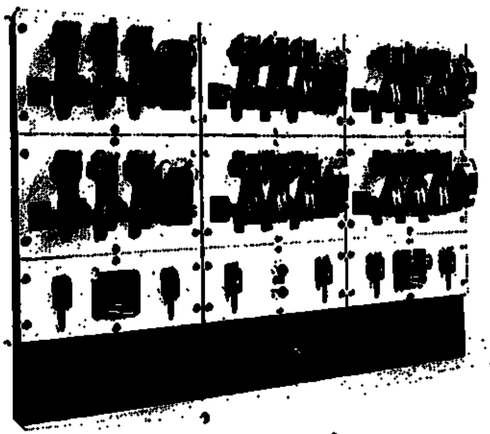
One of the greatest advantages of the electric motor in comparison with other machines for power production is that it is self-regulating as regards the power absorbed. When running it adapts itself automatically to the requirements of the machine it is driving and without any special regulator it absorbs more energy from the supply when the driven machine requires it, reducing the demand when the requirements fall. Setting to work must, however, always be made by the help of special arrangements known as starting apparatus in order that the rush of current taken may not cause undue disturbance to the supply system or be damaging to the motor itself. The function of the starting apparatus is accordingly to reduce the current when first connecting to the line so that this is maintained within certain limits, at the same time as by simple means it allows the motor to develop the best possible torque so as to get through the starting period as quickly as possible. Starting always entails loss of power, and this is another reason for making this period as short as possible. This particularly applies to motors which are used for intermittent work and where starting is frequently repeated. Finally, starting apparatus is in general also employed in stopping the motor and should be so arranged that the equipment is returned to a position suitable for a fresh start as soon as possible.

The most common method of reducing the current during starting is to employ a resistance which is connected in circuit when the motor is joined to the supply. As starting proceeds the resistance is successivly short circuited so that the motor comes up to full speed. This method is used almost exclusively in the case of D.C. motors which are not started by direct switching on to the line or by special regulating machines. For A.C. motors other methods come into question as for instance auto-starters, hysteresis and eddycurrent starters but these have the effect of either reducing the starting torque or adversely effecting the power factor and efficiency and on this account it is not always possible to employ them.

The constructional details and arrangement of automatic starting devices are particularly varied and it is quite natural that this particular field offers considerable scope for new ideas and inventions. Nearly all the methods which can possibly be imagined have been tried out in order to make a motor self-starting. In the case of automatic starters, however, as in the case of many other pieces of apparatus the best results are obtained by modification and development of designs which have previously given good service. It is clear, therefore, that many of the details used have been borrowed from manually operated starters. In certain cases, however, new designs must be developed as, for instance, the contactors previously described and a number of different relays including current limiting relays, shunt relays *etc.* which have taken the place of muscular energy and human initiative during starting. Resistance designs can,

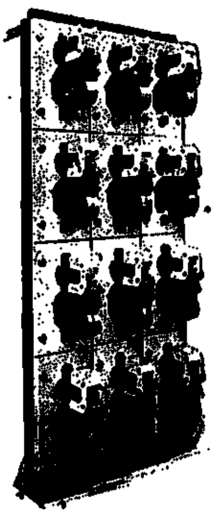


Contactor board with type AEV for 6 three-phase motors 125 h.p., 400 volts, for electric shovel.

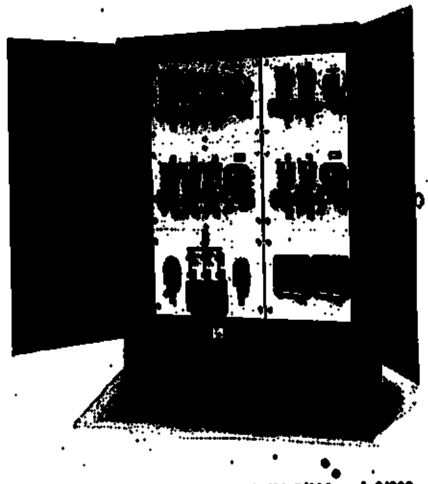


Contactor board with type AEV 3/600 for automatic slip regulating resistance for rolling mill motor.

Contactor board with type AEV 3/350 and 2/350 on metal bases, for dredger.



Contactor board with type AEL 1/600 for derrick motor.

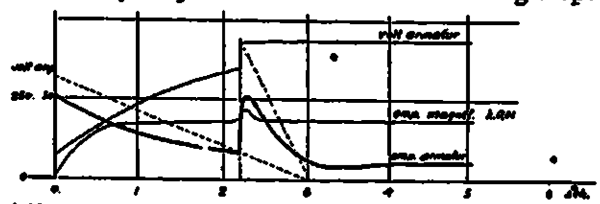


Contactor board with type AEV 3/200 and 2/200 enclosed in a sheet-iron case, for hoisting table motor in a three high rolling mill.

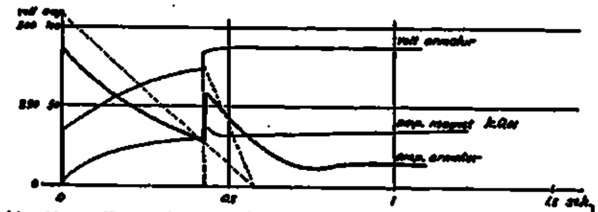
Contactor board with type AEL 1/350 for auxiliary rolling mill motor.

of course, be taken without alteration from other apparatus and it is only the division into different steps which requires to be altered.

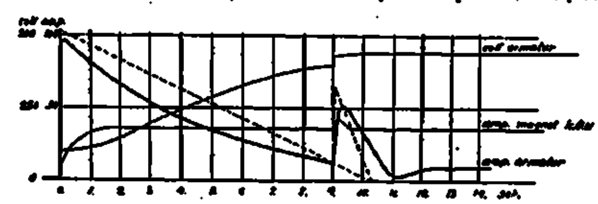
When starters are operated manually it is customary to provide a number of starting steps.



a) Motor K 4, 8 h.p., 440 volts, 2,300 r.p.m., driving Schlotter ventilator.



b) Motor K 4 with Prony brake. Brake input 10 h.p. at 2,300 r.p.m.



c) Motor K 4 direct coupled to flywheel $GD^2 = 6.7$ kgm², 2,800 r.p.m.

Volt, amp = volts, amps. Volt armatur = volts armature. Amp. magnet k 0.m = amps. field k 0.m. Amp. armatur = amps. armature. Sek. = secs.

Fig. 16. Oscillograms showing automatic starting of electric motors.

This is done partly so that the current surges need not be too great and partly because a large number of steps make necessary a more extended movement of the starting handle and make it easier to give an evenly extended time during starting. In the case of manual operation it has even become usual to arrange so called step by step operation which ensures that starting may not be effected too quickly with consequent risk of damaging the motor and resistance.

The conditions are quite different when automatic starting is used. Here the arrangement employed is the determining factor for the most suitable intervals of time between the cutting out of the resistance steps. A greater factor of safety against damage to the motor and apparatus is obtained and at the same time the necessary number of resistance steps can be reduced to a minimum and accordingly the lowest manufacturing costs obtained. In addition it has been found that the values of the current surges, estimated when calculating the starting resistance are in practice considerably lower in the case of automatic starters.

Among the manifold methods which can be used for operating automatic starting gear, the three following have been proved to be the most reliable and economical.

1. The EMF for the motor which increases proportionally with the speed is caused to provide the impulse for the starter.

2. The starting current which for a given resistance in the motor circuit decreases with increasing speed is made to operate a sensitive relay thereby determining the speed of starting.

3. The motor is arranged to start in a predetermined time.

The use of any of the above three methods depends on the machine which the motor is to drive. In order to obtain a good automatic starting action the starter must, as far as possible, be suited to the torque curve of the motor and to the starting characteristics of the driven machine. In this way only can a dependable and economical arrangement be ensured. On this account a combination of two or more of the above methods is often employed.

A number of experimental investigations have been carried out by Asea in order to determine the most suitable number of steps on starters for different sizes of motor and the manner in which the resistance should be divided up. Some curves are given in fig. 16 to show the degree to which an automatic starter can adapt itself to different starting characteristics. These curves also show the extent to which the current surges calculated from the resistance and pressure, exceed the values obtained in actual practice. These values are shown by dotted lines in the figure. For the experiments in question, the motor used was a K 4, 8 h.p., 2,300 r.p.m., 440 volts. Three different cases have been considered.

Case 1. The motor was direct connected to a Schlotter ventilator of type SV (fig. 16 a).

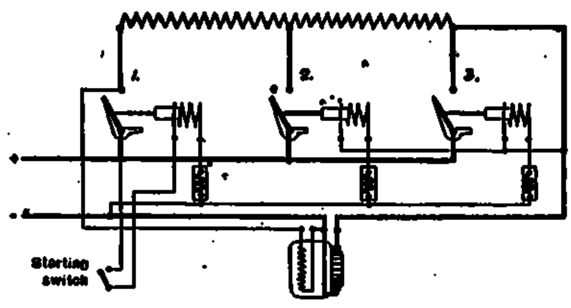


Fig. 17. Diagram showing automatic starter working on the EMF principle.

Case 2. The motor was started with constant torque but not against any extra flywheel effect (Prony brake) (fig. 16 b).

Case 3. The motor was made to start against a relatively high flywheel capacity (fig. 16 c).

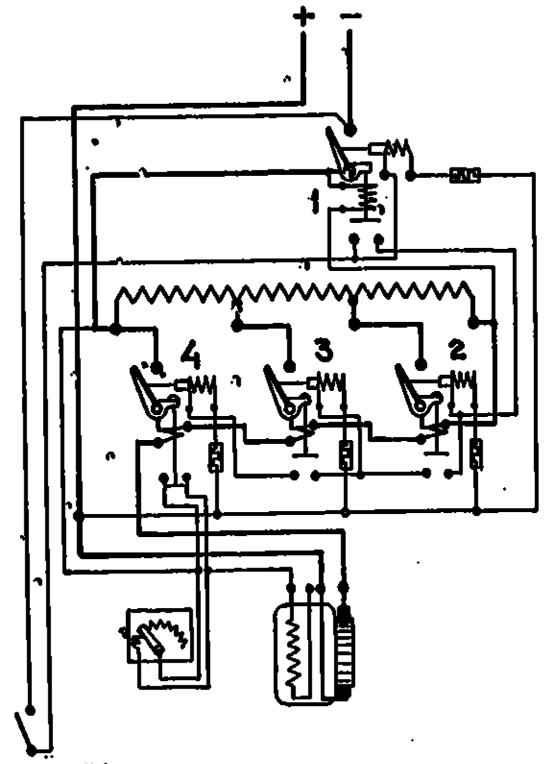
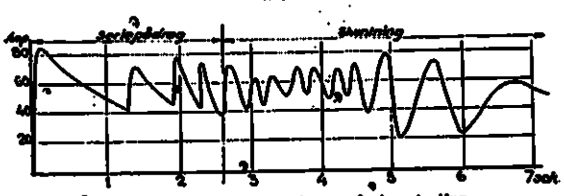


Fig. 18 a. Diagram of automatic starter working on the current limiting principle.



Amp. = Amps. Seriepådrag = Series starting. Shuntning = Shunt control. Sek. = Secs.

Starting on 20 h.p. D.C. motor with flywheel effect at 40 amps. set current in the armature in the final field position. Connections in accordance with fig. 3 a.

Fig. 18 b. Oscillogram showing automatic start with series starter and shunt regulator, up to 1800 r.p.m.

In the above cases experiments were made with different ohmic values of the starting resistances. The magnitude is chiefly limited by the allowable starting current rush and the commutation of the motor. The time interval for short circuiting the resistance depends on the load on the motor and also on the commutation characteristics. A not unimportant factor in the choice of the number of steps is also the character of the supply. Very often the occurrence of heavy current rushes gives rise to flickering of lamps, e.g. when a pump motor equipped with an automatic starter is started up and the number of steps is small. No other disadvantage should, however, occur if the steps are correctly proportioned. It is possible without any risk and with only the disadvantage of a little flickering of the light, which is of short duration, to start motors up to 10 h.p. in size with only one resistance step.

EMF Methods. In the case of starters up to 10 h.p. it is practically universal to make use of the EMF of the motor for giving the starting impulse. Starters of this type are the simplest arrangements for automatic starting and the principle of the device is shown in fig. 17. In the figure an arrangement is shown for starting in two stages. By closing the operating contact the main switch (1) is closed. The motor then starts and when the armature voltage has increased to about 50 % of the normal, a current sufficiently large traverses the coil of the contactor (2) which is connected across the brushes to close this contactor. This short circuits part of the starting resistance and the motor is further accelerated by the increased armature current. When the voltage has increased to about 80 % the last contactor closes, this being connected exactly like the former but so adjusted as not to close until this voltage is reached. The starting resistance is now completely disconnected and the motor runs normally. This method has much to recommend it on account of simplicity, starting being effected without any special operating relays or interlocking contacts. A disadvantage is the difficulty which exists in getting the contactors to close at a definite voltage, since the coils of the electro magnets are exceedingly sensitive to temperature and voltage variation. A maximum of three steps

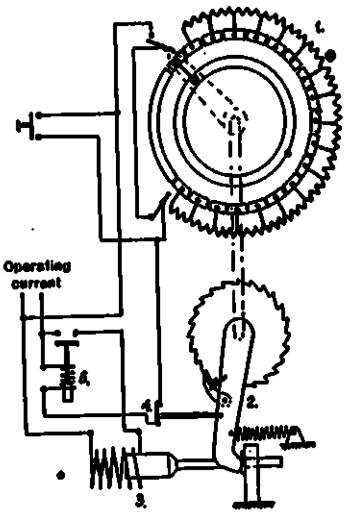


Fig. 19. Schematic diagram of solenoid mechanism.

in the starting may be recorded as a limiting number. Should a larger number of steps be desirable on account of the size of the motor or the sensitivity of the supply to current surges

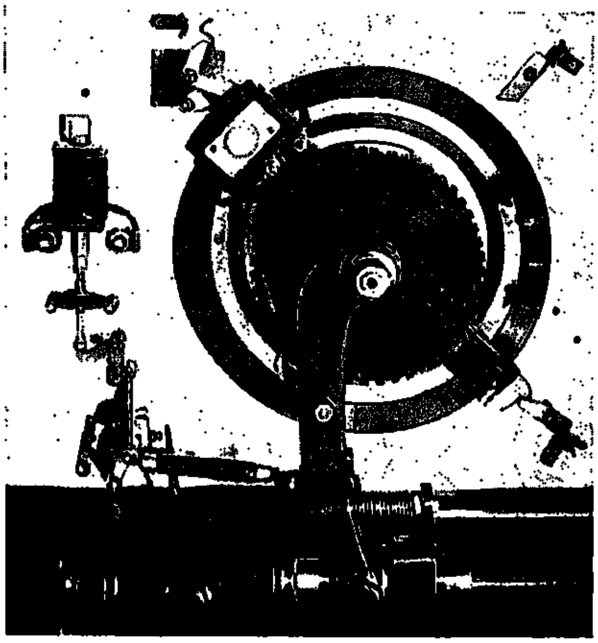


Fig. 20. Regulator panel with solenoid mechanism.

it is more suitable to employ one of the following methods.

Current Limiting Methods. A very reliable and simple method is to use a series relay for giving the requisite impulses. The coil of the relay is traversed by the armature current of the motor which holds back the core of the relay as long as the current exceeds a given value. When the starting current due to the acceleration of the motor sinks below this limiting value the core is released and a contactor closed. This arrangement can be used for the successive short circuiting of resistance steps. The current limiting relay can be made to work in a very exact manner. Tests have shown that with the strength of current only 1 % above the limiting value, the core is retained quite positively even if the relay is subjected to heavy vibration. Such a relay has the advantage that it can also be used for A.C. and the core can be released with the same precision as in the case of D.C.

The current limiting relay can be interlocked and operated mechanically or electrically with the contactors so that only one contactor in its proper order is closed. In fig. 18 is shown a system commonly employed for such a starting arrangement. Each contactor is provided with a current limiting relay. This is placed underneath the contactor and mechanically connected with it. Starting is commenced by pressing a push button, by a float switch or some other operating switch which closes the circuit of the operating coil for the main contactor (1). This shuts and closes the motor circuit. The main contactor has a voltage relay mechanically interlocked with it and this is released when the main contactor closes. The coil and voltage relay is in parallel with the starter resistance and its core is held back as long as the resistance absorbs the chief part of the line voltage. As the motor picks up speed, the voltage across the coil of the relay accordingly sinks and when a suitable limit is reached, the core of the relay is released and completes the operating circuit for the next contactor (2). This closes and short circuits another step of the resistance. Under this contactor is placed a current limiting relay which is released when the contactor closes. This works on the current limiting principle and falls out when the minimum current has been reached closing the operating circuit for the next contactor *etc.* until the starting resistance has been completely short circuited.

With this type of starter an additional series relay can be used with advantage which comes into operation when the last resistance step has been cut out. It is used for periodically connecting and disconnecting the field resistance of a shunt motor so that it is automatically accelerated up to a predetermined speed. The relay works on a principle similar to that of a Tirril regulator but considerably slower. In fig. 18 b is shown the starting curve for an automatic starter operating with a series start in 4 steps and providing afterwards for speed acceleration by introducing shunt resistance with series relays.

Automatic starting in constant time. A particularly good self-acting starting apparatus can be made on the constant starting time principle.

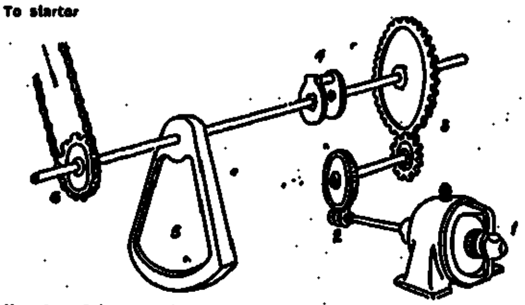


Fig. 21. Schematic drawing of balance weight mechanism.

The time for starting is so chosen that the motor under normal conditions is so accelerated that the current sinks to a suitably low value on each step before the next step is made. The method is particularly applicable to motors which always start under the same conditions and where it is not necessary to effect a start in the shortest possible time. An ordinary starter

of the hand operated pattern can be used, the manual power being displaced by a small motor or a solenoid device. Such starters should be designed with a mechanism providing for instantaneous operation between the various steps if they are of the face plate pattern. If the starter is furnished with knife switches for cutting out the starting steps some arrangement must be made to provide sufficient energy at the moment of closing. Two types of operating gear have been developed by Asea, namely a solenoid mechanism for face plate starters and a balance weight mechanism for knife switch starters.

Fig. 19 is a diagramatic representation of a solenoid mechanism, a photograph of the same arrangement being shown in fig. 20. The arm (1) of the face plate starter is moved by an operating lever (2) by means of a sprocket wheel and pawl. The operating lever is moved by a solenoid (3). When the solenoid is excited the core is attracted and the lever turned. On breaking the operating current core and lever are returned to the zero position by a spring. A reciprocating motion is then set up through a limiting contact (4) which breaks current to an intermediate relay (5) when the core is in its position of furthest displacement and closes the circuit again when the core is returned to its original position. By means of limiting contacts on the starter face plate the periodic motion is arrested in both the "full on" and "stop" positions.

Fig. 21 is the schematic diagram of a balance weight mechanism. Operating power is provided by a small motor (1). By means of a worm gear (2) and a reduction gear (3) the speed of the motor is reduced to about 5 r.p.m. By means of a claw coupling (4) a weight (5) is lifted up. When this weight passes through its highest position it overbalances and falls freely to its lowest position, moving with it the chain wheel (6), by which the operating handle of a standard pattern of starter is turned. By this means instantaneous closing of the operating knife switches is obtained. Fig. 22 shows such a balance weight mechanism combined with a standard starter. Both these types can be used for operating either D.C. or A.C. starters. It often happens that the starting time must be considerably drawn out. Particularly in the case of equipments which have considerable flywheel effect *e.g.* rolling mills or the motor generators of Ilgner sets and the starting mechanism can then be combined with a current limiting relay. As long as the starting current does not exceed the allowable value, the starting mechanism continues to act but if the predetermined value is overstepped, the relay comes into operation and arrests the starting until the current has sunk sufficiently, after which the starting operation is allowed to continue.

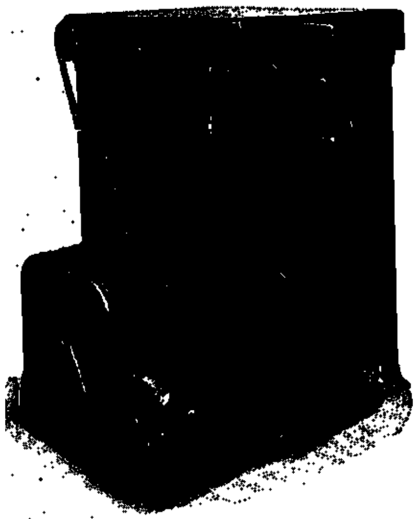


Fig. 22. Oil immersed starter type PTOK with balance weight mechanism.

AUTOMATIC DRIVE OF CENTRIFUGES.

Summary. The general conditions which come into question with centrifuges are treated with reference to the production of a satisfactory automatic equipment. In order to discover the most suitable power supply, a number of experiments have been carried out and the results obtained are used for a critical comparison between A.C. and D.C. The results show that D.C. has overwhelming advantages over A.C. Lastly, a description is given of an automatic system developed by Asea for driving sugar centrifuges.

A. For driving high speed centrifuges a choice can be made from any of the following methods.

1. D.C. shunt motors.
2. Induction motors.
3. Water turbines (Pelton wheels).

The common practice in Sweden for some time was to employ water turbines but these are now becoming obsolete. The question of the most suitable system of electric drive is accordingly important when old plants are being brought up to date, but even when new plants are being installed careful consideration must be given to the same point, irrespective of the fact that one system may already be in use in the same factory. The relative advantages of D.C. shunt motors and three-phase motors must be considered from the point of view of overall efficiency and consequent economy in power consumption. Naturally, all charges must be taken into account, including capital costs, running and maintenance costs together with the saving to be effected in attendance by employing automatic drive.

In the following, attention is chiefly centred on group driven installations which are used in sugar factories for the refining of raw sugar. There is, however, no reason why such equipments should not be used either singly or in groups in other industries such as, for example, chemical processes, paper works, certain textile operations *etc.*

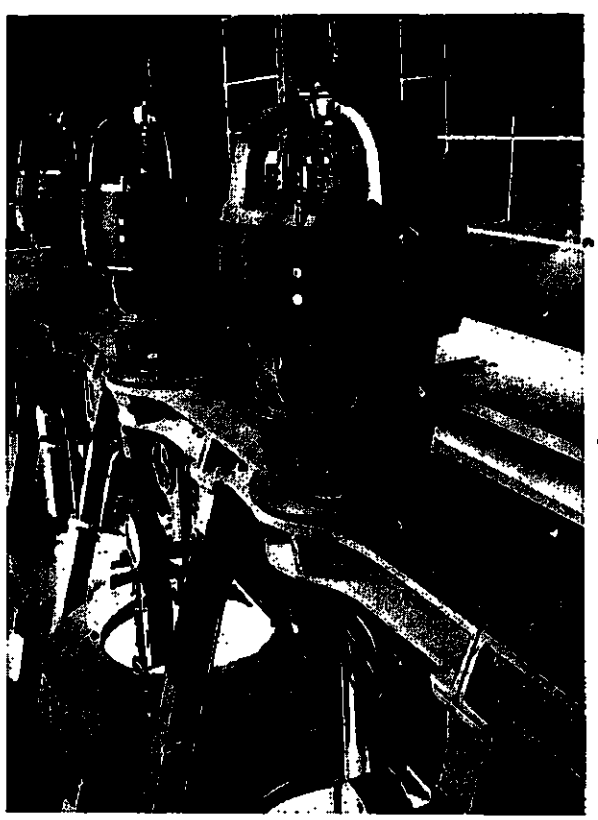


Fig. 23. Centrifuge motors.

In the sugar industry centrifuges hung vertically are chiefly employed. This is on account of the simple and easy manner in which the syrup can be introduced and removed. Centrifuges of this type have very small frictional losses. They are connected directly to the motor shafts and the general appearance of a group of centrifuges constructed in this manner can be gathered from fig. 23. The basket of the centrifuge is supported from a single bearing and is free to take up any position like a conical pendulum. By careful balancing the movement can be adjusted and can be made completely stable up to the highest speeds. The motor is mounted above the centrifuge. It is furnished with two bearings and connected to the centrifuge shaft through an expanding coupling. In the axial direction both parts are able to move slightly with respect to one another. This is particularly important, as otherwise any oscillation arising in the centrifuge might easily damage the whole machine.

The action of the centrifuge depends entirely on centrifugal force which is proportional to the square of the speed. The power supply to a centrifuge is dissipated in

1. Friction losses in the bearings, windage and vibration.
2. Acceleration.
3. Work done by the centrifuge.

1. Bearing friction is exceedingly small as all modern vertical centrifuges are furnished with ball bearings. Air friction is, however, of greater importance. This can be regarded as practically proportional to the square of the speed. Finally, losses due to vibration and shaking which are caused by bad balancing often reach a considerable value. In certain cases they can be very large. The friction losses in a standard 48 inch centrifuge when well balanced are not,

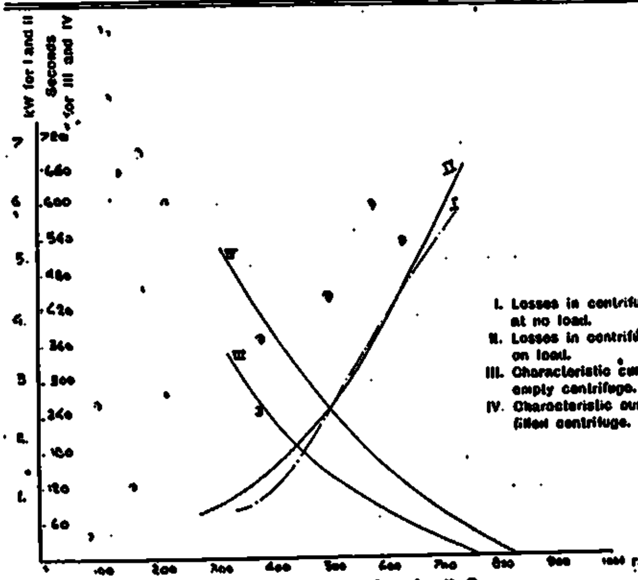


Fig. 24. Sugar centrifuge for D.C.

however, greater than 4 to 4.5 h.p. at 900 r.p.m. (Compare the values in fig. 29 a). A number of tests have shown that they may on occasion be considerably higher than this and values of 8 to 10 h.p. have been measured. In making these experiments the power supplied to the motor has been measured, and the motor losses subtracted. This method is technically quite correct and the increased current taken, often observed in the case of new centrifuges, must always be ascribed to bad balancing or faulty erection of the mechanical parts. To demonstrate the correctness of this, the losses in a centrifuge plant requiring at 800 r.p.m. 10.2 h.p. full and 9 h.p. empty have been determined by a purely mechanical method. The curves obtained are shown in fig. 24 on which curves showing the calculated motor losses and h.p. are also indicated. As will be seen, the losses are considerable and certainly reach 8.9 h.p. and 7.8 h.p. respectively at 800 r.p.m. The difference with empty and full centrifuge is not great. With empty centrifuge the losses are greater at 500/600 r.p.m. and this is ascribed to vibration losses which at this point made themselves

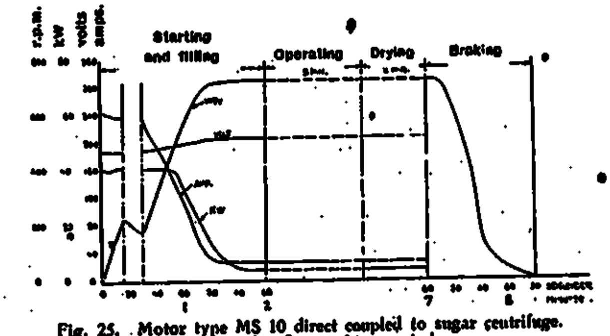


Fig. 25. Motor type MS 10 direct coupled to sugar centrifuge. Curves for the working period.

evident by causing an unusual amount of shaking. This critical speed is not evident in the case of the loaded centrifuge which was stable in running up to the highest speed, although even in this case there was a considerabe amount of shaking.

2. The energy required for accelerating the centrifuge from rest up to the maximum speed is considerable and in the case of centrifuges with normal losses, and with working periods under 10 minutes, represents the greater part of the power.

3. The remaining part of the energy is used up in so called centrifugal work. Some energy is absorbed in the syrup itself and some of the contents is thrown out, representing a loss of rotational energy, *etc.*

In the case of a working period made up of 3 minutes starting, 3 minutes running and 1 minute braking, = 7 minutes, the following energy consumptions have been measured.

Friction losses	0.300 kWh
Rotational energy........................	0.380 »
Remaining losses	0.100 »
Total energy supplied	0.780 kWh

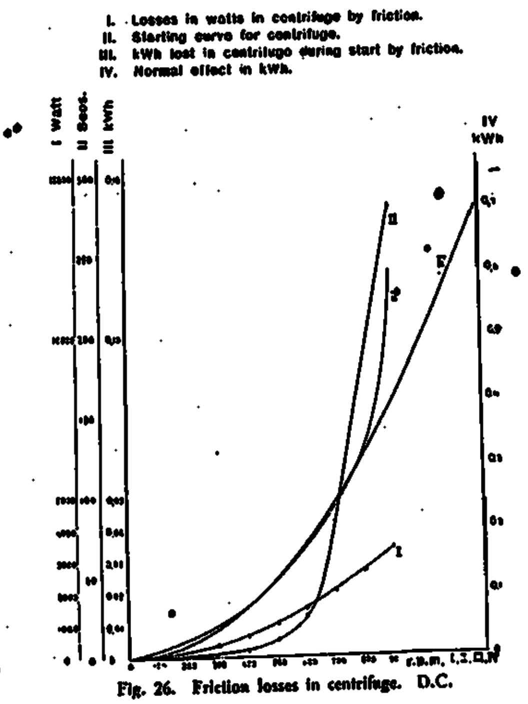


Fig. 26. Friction losses in centrifuge. D.C.

It is seen accordingly that the rotational energy which remains in a centrifuge when the braking period commences is approximately 40 % of the whole of the energy supplied. Since the

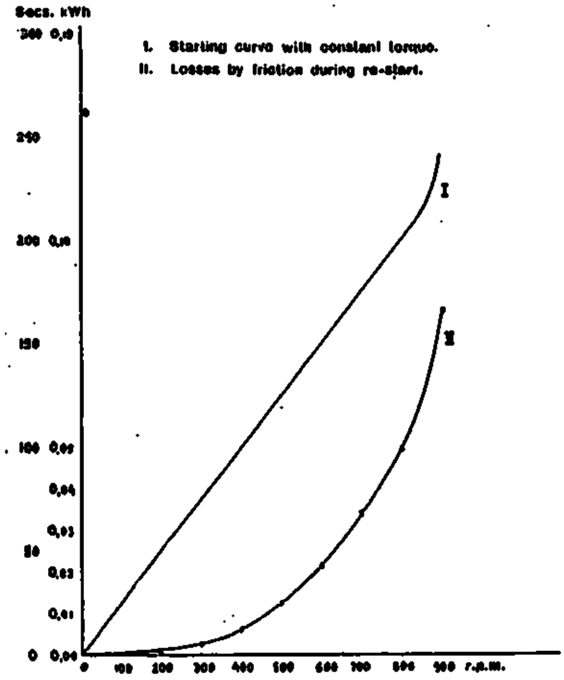


Fig. 27. Calculated starting curves for A.C. centrifuge.

rotational energy or flywheel effect can easily be reconverted into electrical energy the idea of employing it in this way immediately arises. When a mechanical brake is used it is entirely lost, and at the same time the shoes and other wearing parts of the brake are rapidly destroyed. Suitable regenerative braking can be arranged by simple means with D.C. shunt motors while with induction motors a similar arrangement can not be so easily applied.

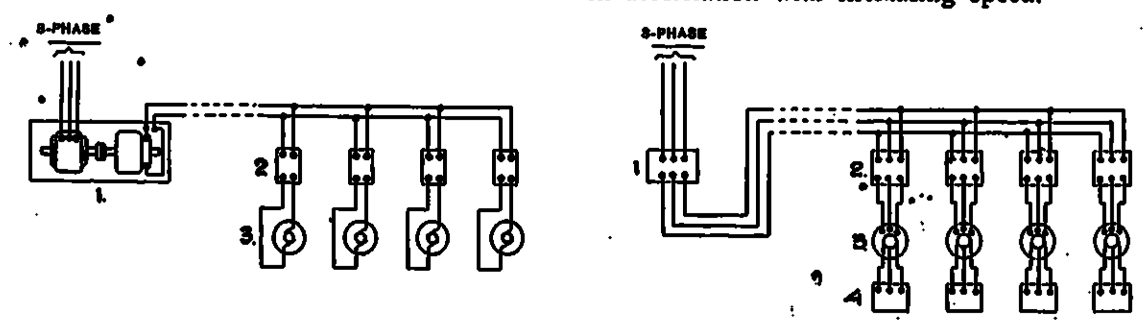
B. The electrical systems between which a choice must be made are:

1) D.C. shunt motors with a large range of shunt regulation (300 to 900 r.p.m.) and regenerative braking from 900 to 350 r.p.m. Starting and stopping is made fully automatic.

2) A.C. induction motors which may either be a) started by direct switching on to the line or b) started with the use of a secondary resistance which is cut out by hand or automatically. With the former arrangement a very high current and a heavy demand on the supply is made during starting (see fig. 25) while the latter gives a starting curve similar to that with a D.C. motor and starter (compare fig. 29 a).

In order to obtain the necessary information for a comparison between the two systems a number of experiments have been made on centrifuges to measure the losses. Readings have been taken for a 48" vertical centrifuge running normally at 900 r.p.m. and with a load of 400 kgs. of sugar. The centrifuge was driven by an Asea D.C. motor of type KS11. Fig. 26 shows the curves obtained. Assuming that the same centrifuge had been driven by an induction motor the curves in fig. 27 have been calculated making use of suitable values taken from the curves in fig. 26.

The difference in the conditions of starting with the two types of motor is clear from figs. 26 and 27 as it will be seen that the speed with an A.C. motor increases in a practically linear form while with the D.C. motor the speed rises much more slowly. This is explained by the fact that the energy absorbed due to the flywheel effect of the centrifuge, increases as the square of the speed and since the induction motor starts with constant torque the energy supplied by the motor to the centrifuge also increases as the square of the speed. On the other hand the D.C. motor, as soon as it reaches the shunt regulating range supplies only a constant output to the centrifuge which corresponds to a decrease in acceleration with increasing speed.

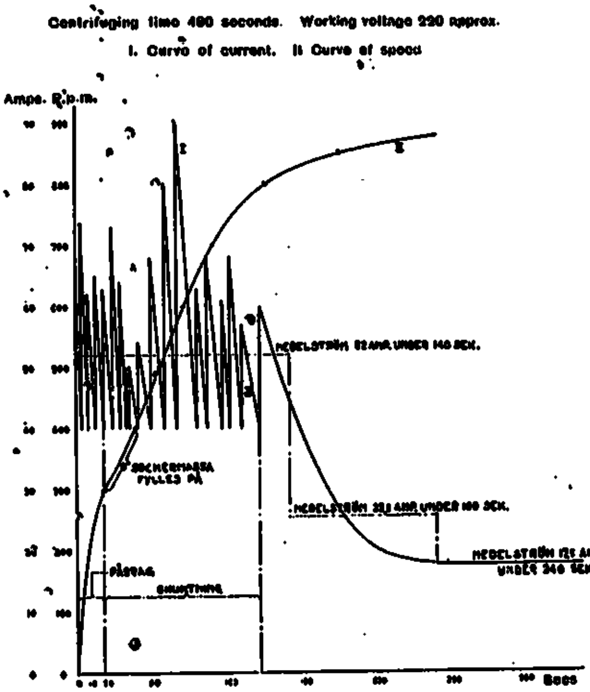


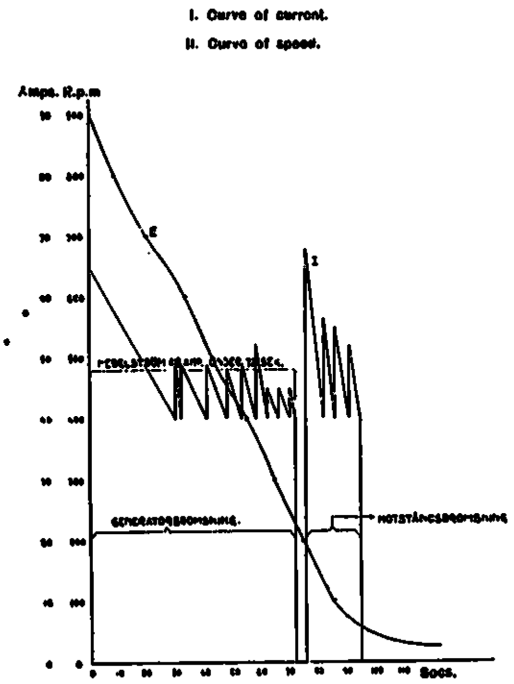
D.C. SYSTEM.
1. Motor generator 2. Starter. 3. Centrifuge motors.

A.C. SYSTEM.
1. Switchcase. 2. Motor switches. 3. Centrifuge motors. 4. Rotor starters.

Fig. 28. Diagram showing centrifuge equipments.

If, however, the losses during starting are compared, the D.C. equipment will be found much more favourable in performance than the A.C. equipment. The D.C. motor during starting has losses which are no greater than when





Medelström 52 amp. under 140 sek. = *Average current 52 amps. for 140 seconds. Sockermassa fylles på* = *Liquor introduced. Pådrag* = *Starting. Shuntning* = *Shunt regulating. Generatorbromsning* = *Regenerative braking. Motståndsbromsning* = *Resistance braking.*

Fig. 29 a. Starting curves for centrifuge No. 1.

Fig. 29 b. Braking curves for centrifuge No. 1.

running normally while the A.C. motor only makes use of about half the amount of energy taken from the supply during the time of starting. During actual running the losses are much alike while when the braking period is reached the D.C. equipment again gives more favourable results. By regenerative braking in the case of the D.C. motor a not inconsiderable amount of the energy taken from the supply for purposes of acceleration is recovered. Theoretically

$$A = A_{\text{total}} \frac{n_1^2 - n_2^2}{n_1^2}$$

is recovered. (We have A_{total} the whole of the energy accumulated in the system, n_1 = the normal speed, n_2 = the speed down to which braking is effected). In the equipments here described $n_1 = 900$ and $n_2 = 350$ accordingly

$$A = 0.85 \cdot A_{\text{total}}$$

and accordingly 85 % of the energy supplied to the centrifuge can be recovered. The energy actually obtained in accordance with recorded measurements is, however, only 56 % due to the losses in the centrifuge and motor during the braking period. (Compare fig. 29 b).

As a comparison the two plants shown schematically in fig. 28 may now be recorded side by side. In the case of the D.C. equipment it has been assumed that only a three-phase supply is available. Accordingly, if a D.C. supply should already exist the result would naturally be much more favourable to D.C.

The following losses are assumed in the motor and cables:

D.C.

Motor generator	16.6 %
Cables	5 %
Motor	13 %

A.C.

Cables	5 %
Motor	13 %

For D.C. we have the following:

Starting centrifuge 0—900 r.p.m.	0.530	kWh
Losses in motor and series resistance	0.149	„
Total energy supplied during 3 minutes running	0.193	„
Total	0.872	kWh

If the energy recovered during regenerative braking, namely 0.210 kWh is subtracted from this and the losses in the cables and motor generator taken into account the energy supplied to the centrifuge during a working period is 0.834 kWh.

With A.C. we have the following correspondingly:

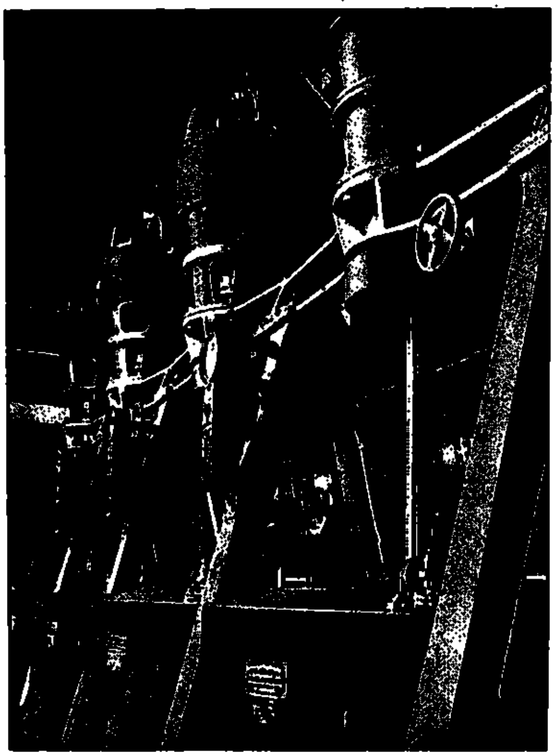


Fig. 30. Sugar centrifuges with equipment for automatic electric drive.

Starting centrifuge 0—900 r.p.m.	0.475	kWh
Losses in rotor circuit	0.475	„
Losses in motor (13 %)	0.142	„
Total energy supplied during 3 minutes running	0.193	„
Total	1.285	kWh

If the losses in the line (5 %) are included the total energy consumed in one centrifuge during one working period is 1.34 kWh.

An A.C. centrifuge equipment accordingly consumes 0.5 kWh or 60 % more than a D.C. equipment. This may be a very expensive matter as will be clear from the following calculation. Assuming a plant including 15 centrifuges operating with 7 working periods per hour, an 8 hour day and 200 working days per year, the increased consumption in the case of A.C. is 83,400 kWh.

These figures show the advantage of using D.C. even if a special converter must be installed and the installation costs for a D.C. equipment much increased beyond those for an A.C. equipment.

C. Based on experience gained with large number of plants, centrifuge equipments are now supplied by Asea for automatic working in the following manner:

1. Starting is automatic using series resistance up to 300 r.p.m. and shunt regulation up to normal speed.

2. Stopping is also automatic, braking first being regenerative down to about 350 r.p.m. after which the speed is brought down to about 50 r.p.m. by the use of a series resistance.

3. The arrangement is fool proof, *i.e.* so designed that incorrect operation is practically excluded. If anything of the sort should occur, the equipment is arranged so that the electrical gear can suffer no damage.

4. No-volt release is provided and the equipment returns to the starting position as soon as the pressure is restored.

All operations are controlled from the working position where a push button box is placed at the side of each centrifuge. This box is furnished with one button for running. There is also an emergency stop button by which the motor can be disconnected from the supply in case of necessity, *e.g.* if the centrifuge should begin to vibrate or run away. Lastly, there is an indicating lamp which lights up when the equipment is ready for a new start, and an ammeter with centre zero giving a deflection to the right when the machine runs as a motor and to the left during regenerative braking.

Figs. 23, 30 and 31 show such an equipment supplied by Asea to a firm of sugar manufacturers (Svenska Sockerfabriks A.-B., Tanto, Stockholm). Fig. 23 shows how the motors are mounted above the centrifuges. Fig. 30 is a view of the working platform where the operator attends to the filling and emptying. In this view

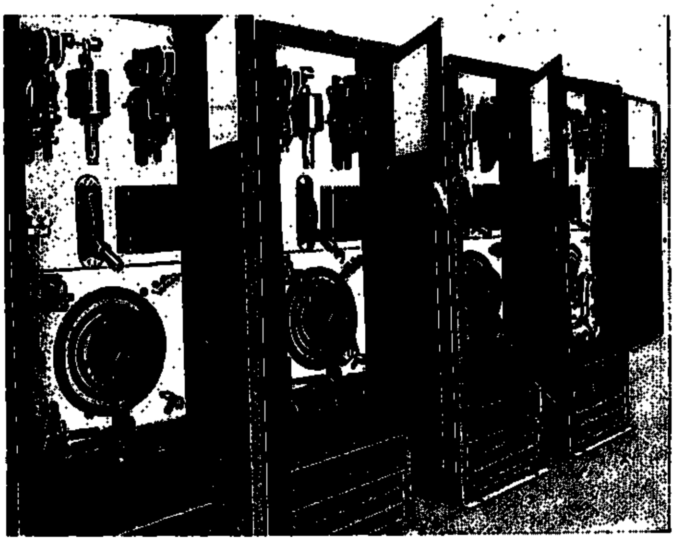


Fig. 31. Operating switchcases for automatic drive of sugar centrifuges.

will be noticed at the side of the centrifuge the push button box referred to above with an ammeter above it. Lastly fig. 31 shows the operating gear mounted in steel switchcases for the automatic drive. The switchcases are erected in a line behind the centrifuges but at a suitable distance therefrom so as to give comfortable room for inspection and maintenance.

As regards the method of running the "run" button is pressed when a start is to be made. The button can be released as soon as the indicating lamp is extinguished showing that automatic start has commenced. Any further depression of this button has no effect at all on the starting apparatus. The operator can devote his whole attention to work on the centrifuge. When the centrifuge comes to the end of the working period, stopping follows through the action of a special time relay (automatic mechanism). This sets the starting apparatus in motion causing the centrifuge to be braked down to its lowest speed. When this has been reached the indicating lamp again lights up. The operator can now empty the centrifuge if necessary bringing it entirely to rest by the mechanical brake.

In certain cases a mechanical emptying arrangement is used for the material. The motor must then run at a low speed and this is obtained by the starting apparatus remaining automatically at the lowest speed position.

The ammeter provided enables the various phases of the working period to be observed in the current consumed at each instant to be checked. Fig. 29 a and b show the starting and breaking curves during a working period.

Among the advantages of a fully automatic D.C. equipment may be mentioned the following:

1. Low current consumption.

2. The time of the operator can be fully taken up in productive work. The only time which has to be given to the electrical part is when the starting button is depressed. One man can accordingly attend to the greatest possible number of centrifuges.

3. By the introduction of an integrating meter, *e.g.* kWh meter or ampere hour meter, the Works Manager is able to obtain a complete check on the running without having reference to the foreman. Such metering shows not only the power consumed but is a measure of the diligence of the operators and is accordingly a valuable aid in the speeding up of the factory.

STAL TURBO GENERATORS FOR COMBINED A.C. AND D.C. SUPPLY.

During the last twenty years turbo generators have almost entirely displaced other steam plant, at any rate for units of any magnitude and have attained to a quite unexpected development. The great progress made has, however, been somewhat one-sided as steam turbines have been used almost exclusively for driving alternators. D.C. turbo generators have never succeeded in making themselves very popular.

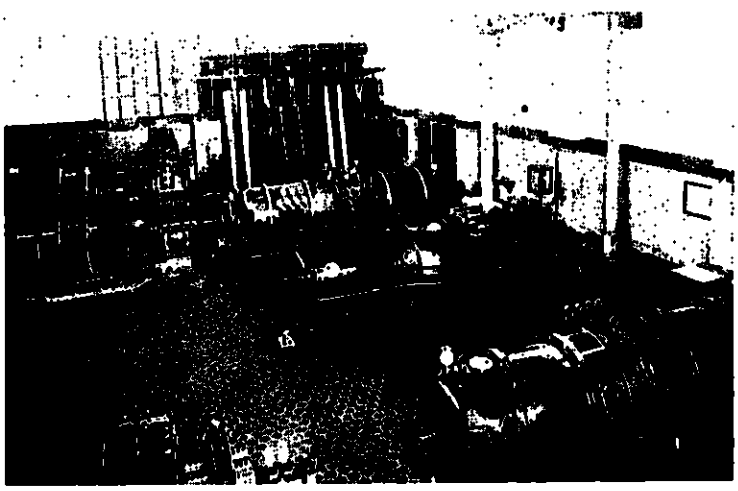


Fig. 1. 1,700, 2,800 and 4,900 kW Stal turbo generators at the Odense Municipal Electricity Works, Odense, Denmark. (The D.C. generator for the last named set is 1,500 kW.)

In many power stations D.C. is required while in the case of a considerable number of industrial undertakings it is a necessity, and requirements have been met by transforming the generated alternating current by means of motor-generators, cascade and rotary converters and also, during the last few years, by mercury vapour rectifiers.

It cannot be denied that such an arrangement may be a satisfactory solution of the problem but at the same time in many cases it is more simple and practical to generate direct for both systems of supply. Such an arrangement is by no means new and has often been employed when Diesel engines have supplied the power. Especially in municipal power stations it is often seen. The D.C. generated is commonly used in the neighbourhood of the station for lighting and also in some cases for traction purposes. The A.C. supply is used in rural districts and is also often fed to large industrial consumers whether situated close to the station or remote from it.

As both supplies are required together, considerable advantages as regards simplicity and efficiency are obtained if they can be produced by a single prime mover. The simplest method which suggests itself is to use the same arrangement which has been employed for Diesel engines, *i.e.* to couple the turbine direct to two machines, an alternator and a D.C. generator. This arrangement has also been employed, the only disadvantage being that a D.C. generator is not so suitable as an alternator for running at the high speeds which are in question. This disadvantage can be overcome by the introduction of a further element of machinery which has been developed to a high state of efficiency during the last few years, namely a reduction gear. There is no need for us to do more than mention the large use which has been made of reduction gears during the last ten years except to point out that we have made it a satisfactory means of overcoming the difficulties previously in the way of a combination drive such as we are now considering. The arrangement we have developed is that of a steam turbine and an alternator which can be designed for high speeds direct coupled, and a D.C. generator connected to the set through a suitable reduction gear.

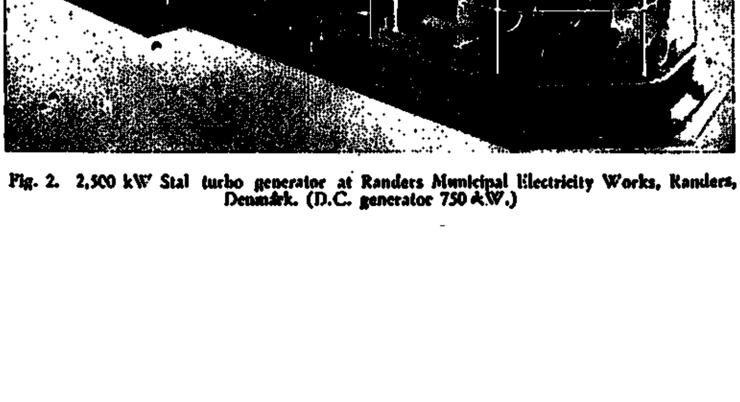


Fig. 2. 2,500 kW Stal turbo generator at Randers Municipal Electricity Works, Randers, Denmark. (D.C. generator 750 kW.)

For some years Stal has been manufacturing turbo generators according to this arrangement and we are able to give some illustrations of plants of this nature. During the short time these sets have been in use they have become very popular and reports regarding their running show that as regards reliability and efficiency great improvement has been obtained by their use.

We may give the following extract from a report by the Municipal Electricity Department of Odense;

»The year 1924—1925 which is the Department's 16th operating year has shown a very satisfactory increase in power consumption. The operating costs are practically the same as for the preceding year, and the outlay for fuel, in spite of somewhat higher price of coal and greatly increased price of fuel oil, has been somewhat reduced. This can be ascribed to an improved efficiency of the steam plant, partly attained by the lower steam consumption of the new turbine unit and partly due to better efficiency of the electrical side of the installation, owing to the fact that the new turbine being provided with a geared D.C. generator meets a considerable proportion of the demand for D.C. energy which formerly necessitated the running of converting plant. In the year under consideration the new turbine installation has been directly responsible for a saving of approximately 950 tons of coal in comparison with the preceding year.»

During the last working year the newly installed turbo generator has generated 9.75 million units, or 71.5% of the 13.65 million units produced by the Power station and to quote again from the Report »the arrangement chosen for the unit embodying the direct coupling of A.C. and D.C. generators has given rise to great advantages, as anticipated, as regards economical working and reliability of the D.C. distribution to the town. By the combined A.C.

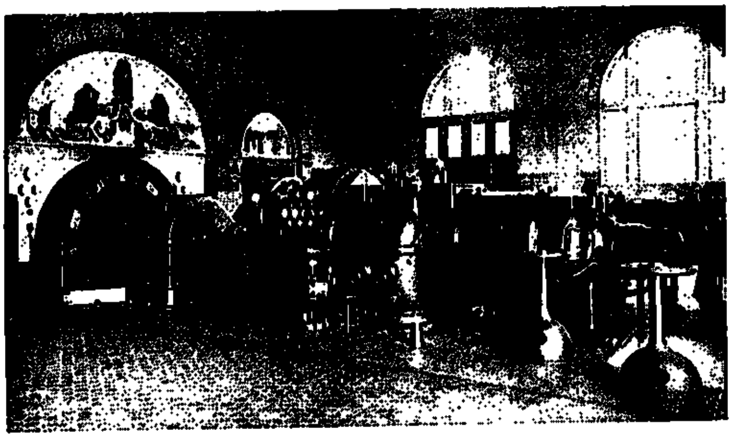


Fig. 3. 4,900 kW Stal turbo generator at Aalborg Municipal Electricity Works, Aalborg, Denmark. (D.C. generator 1,500 kW.) (In the background one 1,400 kW Stal turbo generator.)

and D.C. drive considerable saving in converting losses has been effected and in addition disadvantages caused by the rotary converters frequently falling out of step due to short circuits occurring on the high tension network*) have been overcome.»

When units of this description were first proposed there was a certain amount of doubt in the market as to whether the Stal turbine with its special construction (the double rotation principle) could be adapted for such an arrangement. This fear was due to the opinion that the load on the two halves of the system would differ since both the A.C. generators are exactly alike and the D.C. generator was to be coupled to one side only. This gave rise to the idea that the speed of the heavier loaded side would tend to decrease causing the A.C. generators to fall out of step. The loads on the two halves of the turbine are, however, automatically adjusted to the same value since any lack or excess of mechanical energy from the turbine wheels is equalized by the interchange of electrical energy between the two halves. The two turbine wheels, which are practically identical supply the same

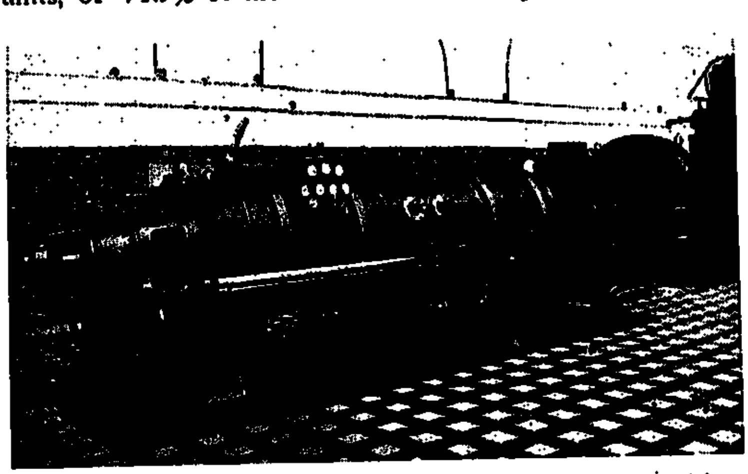


Fig. 4. 2,500 kW Stal turbo generator at Nakskov Municipal Electricity Works, Nakskov, Denmark. (D.C. generator 750 kW.)

*) This distribution network does not belong to the Municipal Electricity Department.

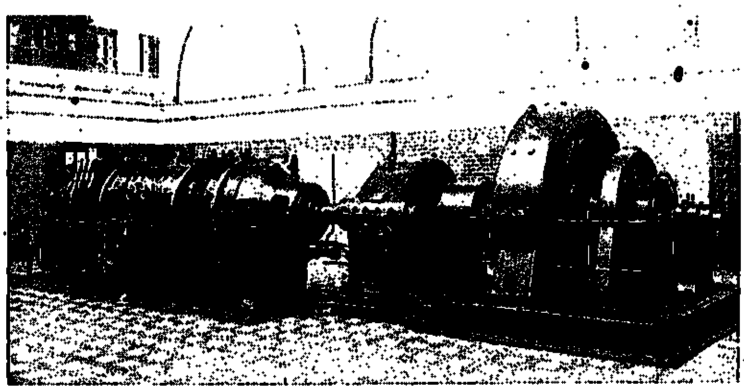


Fig. 5. 2,500 kW Stal turbo generator at Nakskov Municipal Electricity Works, Nakskov, Denmark. (D.C. generator 750 kW.)

amount of power to the generator shafts. Suppose the A.C. generators are running unloaded then half the power for the D.C. generator is supplied direct from one half of the system, while the other half is generated first as A.C. in the opposite generator and transmitted through the generator connections, after which the A.C. machine on the same side as the D.C. generator works as a motor to give the other half of the power. When the A.C. and D.C. loads are equal the last mentioned A.C. generator runs without load. As the rotors are connected in series, this means, however, that they will always have the same ampere-turns so that the generator in question will in this case give a certain kVA output but at $\cos\varphi = 0$. If the A.C. load is increased, this generator will also give useful output, although as long as there is any D.C. load it will always be at a lower power factor, while the other generator will give the greater power component.

It might also be assumed that the automatic synchronizing of the two A.C. generators would be interfered with due to the difference in flywheel effect on the two shafts. The exciter is, however, placed on the free side so that immediately after starting sufficient excitation is obtained for pulling into step. The starting of the combined unit is accordingly just as simple and easy as for any other turbine.

MATERIAL OF UNSURPASSED QUALITY.

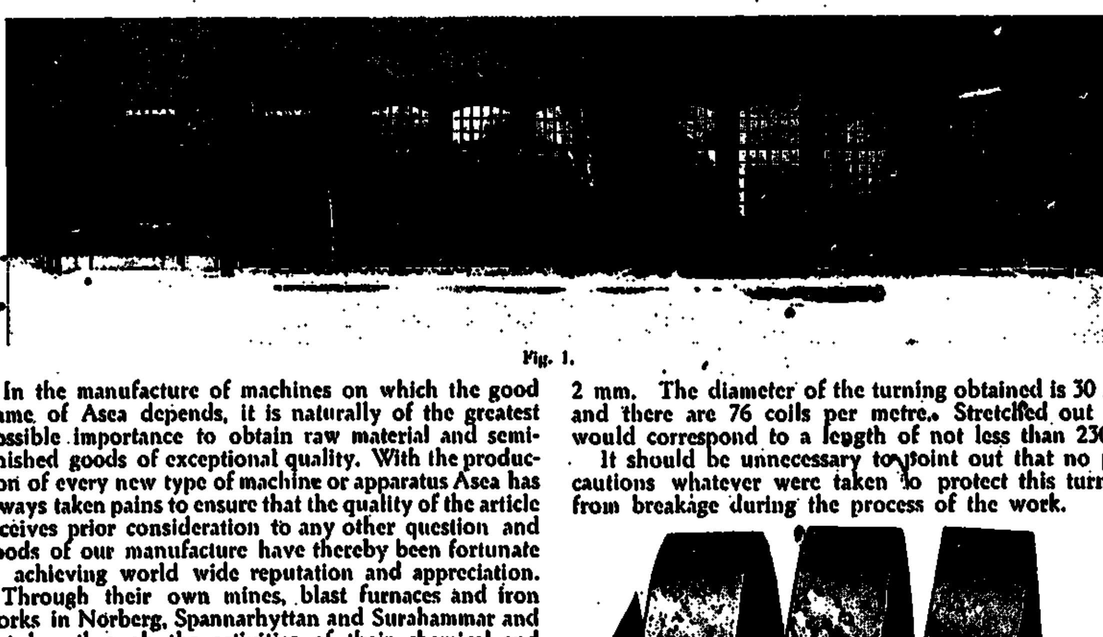


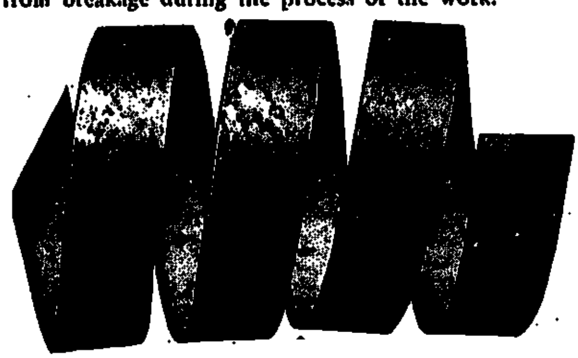
Fig. 1.

In the manufacture of machines on which the good name of Asea depends, it is naturally of the greatest possible importance to obtain raw material and semi-finished goods of exceptional quality. With the production of every new type of machine or apparatus Asea has always taken pains to ensure that the quality of the article receives prior consideration to any other question and goods of our manufacture have thereby been fortunate in achieving world wide reputation and appreciation.

Through their own mines, blast furnaces and iron works in Norberg, Spannarhyttan and Surahammar and not less through the activities of their chemical and metallurgical laboratory, the company can ensure the availability of iron and steel material which will bear comparison with the very best which the world produces.

The illustrations reproduced bear witness to this statement. Fig. 1 shows a continuous turning 30 m in length which was obtained while turning down the shaft forged at the Surahammar Works for one of the generators in the new power station at Hammarfors. The cut was made with a depth of 13 mm and a feed of 2 mm. The diameter of the turning obtained is 30 mm and there are 76 coils per metre. Stretched out this would correspond to a length of not less than 230 m.

It should be unnecessary to point out that no precautions whatever were taken to protect this turning from breakage during the process of the work.



ELECTRIC SHOVEL FOR THE LUOSSAVAARA-KIIRUNAVAARA A.-B., KIRUNA, SWEDEN.

Fig. 1 below shows a converter unit belonging to the electrical equipment of an ore loading machine for Luossavaara-Kiirunavaara A.-B., Kiruna, delivered by Asea.

The suppliers of the complete machine were the Morgårdshammars Mechanical Works Co. who were accordingly responsible for the whole of the mechanical details.

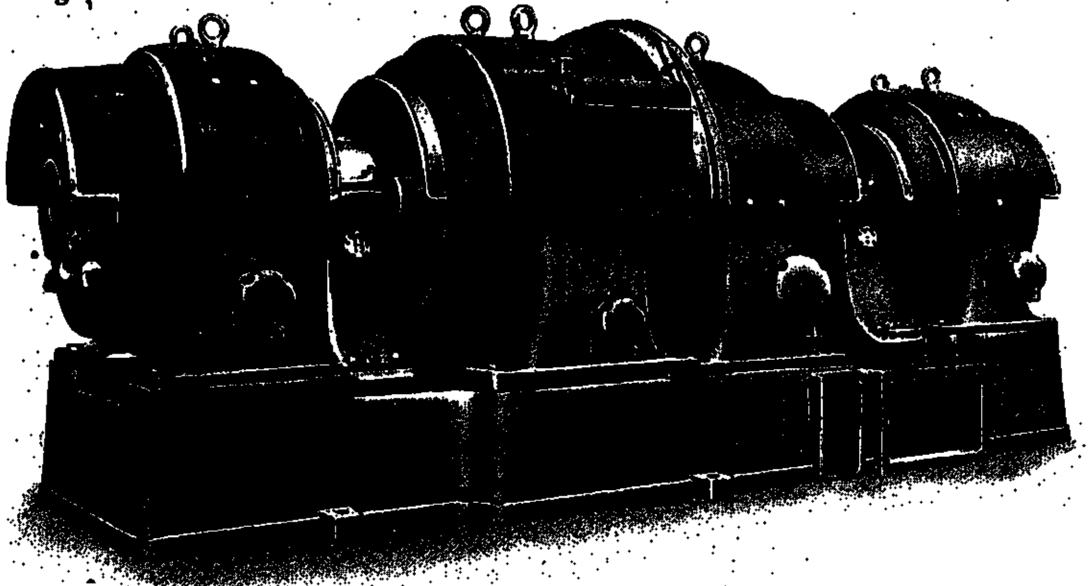


Fig. 1. Motor generator converter set.

The machine in question is both on account of size and design in a special class among similar machines and is worthy of more extended comment than space in this number of the Journal will allow.

We hope later to be in a position to go more fully into the various considerations which make this delivery one of great interest, but for the present we must be content to give a few general data.

The electric shovel, which is of the so called revolving type, has a movable body containing the motor equipment mounted upon an truck frame. The function of the machine is to load the ore blasted out of the Kiirunavaara mountain into the ore trucks in which it is conveyed to the crushers. An idea of the appearance of the machine can be gathered from the second illustration. The jib carries a dipper to which is fixed the digging shovel which has a content of 3 m^3 corresponding to a capacity of about 10 tons of ore. The total weight of the machine is about 250 tons.

As regards the electrical equipment the machine is particularly noteworthy and differs from any hitherto used. The electrical machinery is in fact constructed in accordance with the Ward-Leonard principle.

With regard to the motor equipment four main headings have to be considered *i.e.* machinery for: 1) hoisting, 2) slewing, 3) digging and 4) travelling, all by electric power. The lifting machinery consists of a winch gear with cylindrical rope drum direct coupled to a D.C. motor rated for 160 h.p. at 45 r.p.m. This machinery determines the movement of the dipper and the shovel in the vertical direction. The slewing machinery which is driven by a 110 h.p. D.C. motor running at 510 r.p.m. consists of spur- and backgearings which transfers the movement to a vertical shaft. At the lower end of this shaft is fixed a gear wheel which drives the revolving gear on the truck frame. The slewing machinery causes the complete upper body with jib, dipper and shovel to rotate round the above mentioned vertical shaft.

An 85 h.p. D.C. motor running at 525 r.p.m. drives through a gear the dipper which is supported to the jib by a toothed rack and thus gives the dipper the necessary forward and return motion.

The truck frame is furnished with caterpillar tractors so that the whole machine can move from one place to another. The travelling motion

is given by the hoisting motor which, through a dutch coupling device on the hoisting drum shaft, can be connected to a gear driving the tractor treads.

All the above mentioned driving motors are, as mentioned above, connected according the Ward-Leonard system to the converter unit shown in fig. 1 which is housed in the back of the body and consists of the following machines: One squirrel cage three-phase induction motor, 350 h.p., 2,100 volts, 25 cycles, 720 r.p.m., one compound wound D.C. generator for hoisting, 140 kW, 350 volts, two compound wound D.C. generators each of 87 kW, 330 volts, for the slewing and digging motors. These two generators are mounted on the overhung shaft ends at each end of the unit.

The machines are mounted upon common and heavy bedplate. The stator frames of the machines are of cast steel. Electric power is brought to the machine in the form of three-phase A.C., 2,000—2,200 volts, 25 cycles through a special flexible cable from the pit sub-station. The series windings on the generators are counter-acting so as to limit the torque developed by driving motors to a fixed maximum. For exciting the D.C. machines a separate exciter unit has been provided. The operation of the driving motors in accordance with the Ward-Leonard principle is done by controllers connected in the field circuits and regulating the field current of each generator and thereby the armature voltage supplied to the driving motors. The slewing and digging motors are shunt wound and electrically reversible; the hoisting motor on the other hand being series wound and not being arranged to reverse in normal service. When travelling, however, it can be made to run in either desired direction by employing a special changeover switch.

All machines composing the electrical equipment are in many respects special designs, made necessary by the particularly arduous working conditions under which shovels of this particular type work. Special care has been given in order to secure mechanically stiff and unbreakable constructions and it is to be hoped that the efforts of Asea in this respect will be found entirely successful.

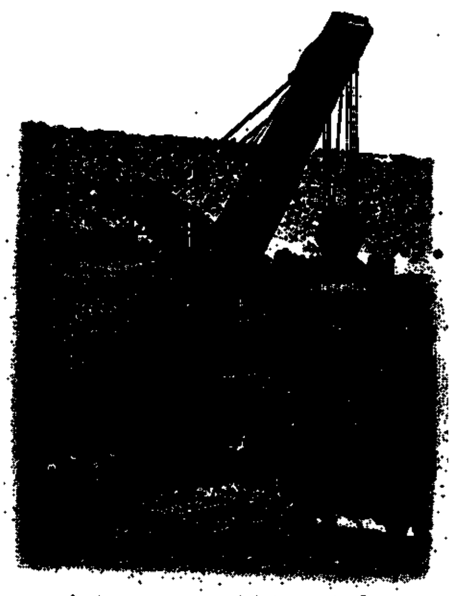


Fig. 2. Electric shovel at test lifting one loaded ore truck.

Vesteras 1927, Westmanlands Allehanda Printing Co.

ASEA-JOURNAL

ALLMANNA SVENSKA
ELEKTRISKA A.B.
VESTERAS — SWEDEN.

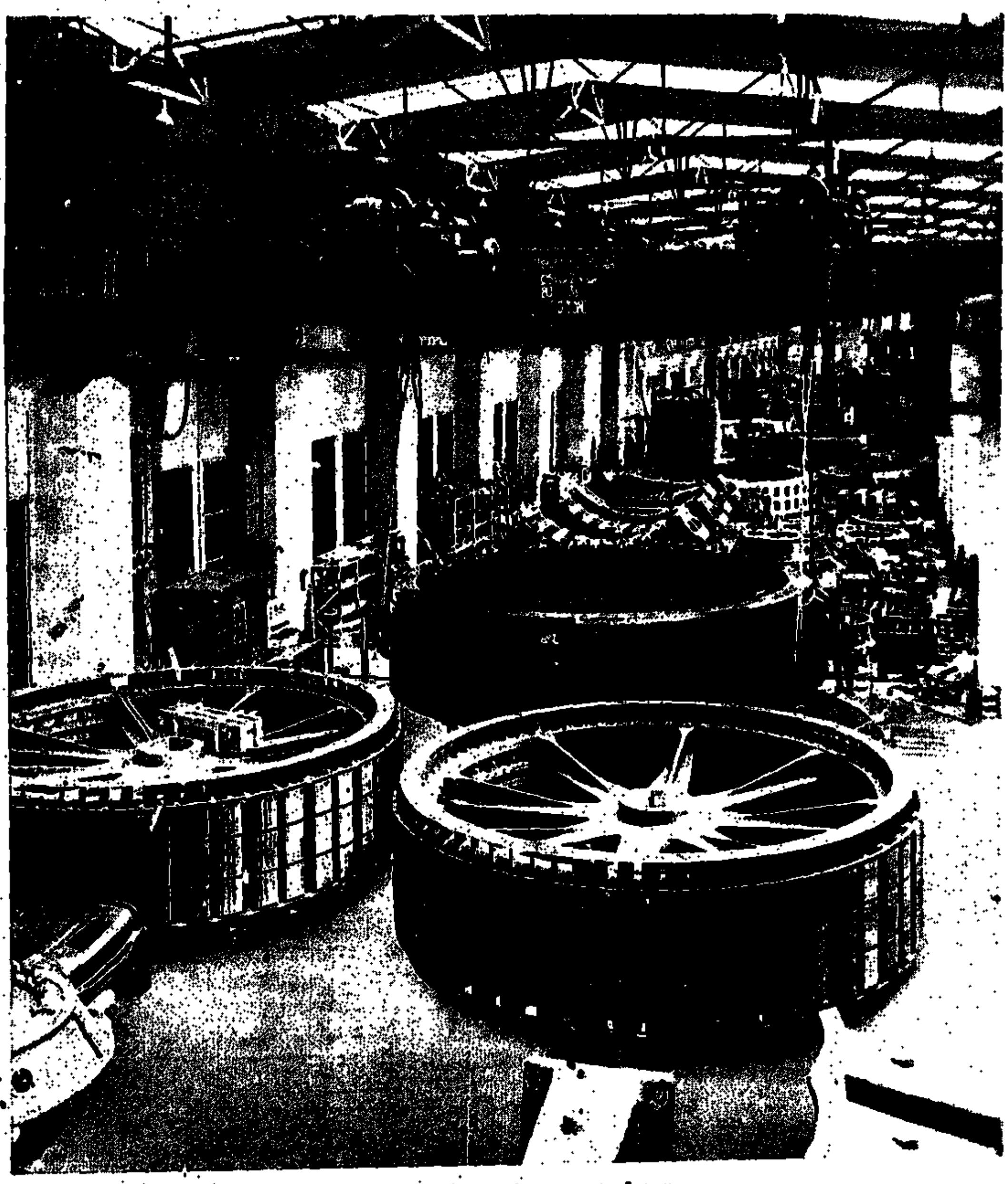
SWEDISH GENERAL
ELECTRIC LTD
8. CHANCERY LANE—LONDON

MONTHLY REVIEW

VOL. IV
1927

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Vesteras, Sweden.

DECEMBER
No. 12



New bay in the Asea large generator factory.

TWO NEW TRAIN LIGHTING SYSTEMS.

Extract from paper read at the Swedish Technical Society's meeting, 18th March, 1927.

There are, of course, a great number of systems for electric lightning on railway trains. The fact that Asea was not content to accept one of systems which are most frequently adopted, as has been done by most other firms, is due to information obtained from different

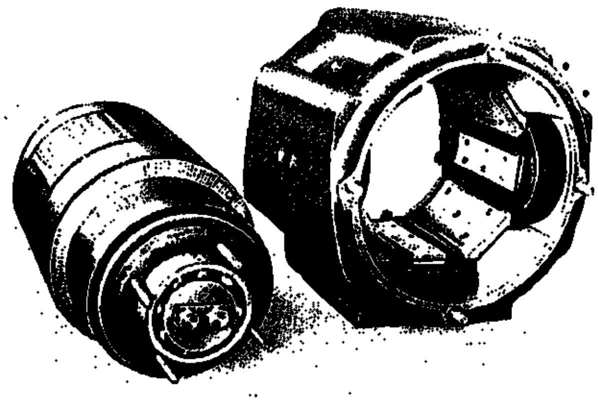


Fig. 1. Rotor and stator of new train lighting machine.

quarters which confirmed the view that none of the systems at present in use can be regarded as ideal and that accordingly there might be a good chance for a new system, if definite advantages could be shown.

A general examination of the systems at present in use indicated that improvements were possible in two directions namely regarding simplicity and effectiveness of action. All the known systems are in fact compromises between the two main points of simplicity and effective action. What is actually required is the following: It is necessary to aim at the generation of two voltages, the one if possible constant for lighting and the other somewhat higher for battery charging. In addition an automatic changeover switch is always required which disconnects the generator and throws the lighting on to the battery, when the speed of the train is low, returning to the original position when the speed of the train rises again above a certain limit.

The generator and the changeover switch are accordingly indispensable. It has been found possible with certain systems to dispense with voltage regulators for the lighting and current regulators for the battery charging current so that these pieces of apparatus can be regarded as complications.

It appears therefore that an advance can be made in two different directions: The one most radical advance is to dispense with all regulators. All regulation should be provided in the generator itself. It should be able to generate in a simple manner a voltage suitable for lighting which will remain constant from a given train speed and in addition a higher voltage for battery charging while the train is running. This would give a system with a generator special in several respects but without any regulators.

The other extreme, however, embodying a D.C. generator of entirely standard design controlled by special regulators also has advantages. If, for example, regulators operating on one system are found unsatisfactory they can be changed for some of different make. Viewed accordingly from the customer's side it is a step involving less binding consequences to go in for a system with a normal generator and automatic regulators. A less radical but not less important step forward can accordingly be made by retaining regulators but making them of a more simple character. Judging by the experience gained by our Railway Department, it appears that in general the regulators are the weak point and therefore if they could be constructed more robust, but not dearer on this account, and with at least equal effectiveness it would appear that a new system on these lines would have good future prospects.

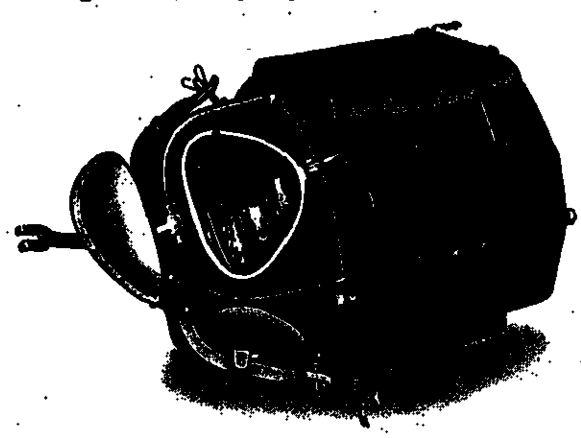


Fig. 2. New train lighting machine assembled.

The matter is accordingly reduced to inventing either a new train lighting generator or a new regulator. I endeavoured myself to carry out the first. Investigating the regulator question Mr Akerman succeeded in inventing a new, and as it seems to me, a very useful and effective piece of apparatus so that there are now two new systems which have been thoroughly investigated.

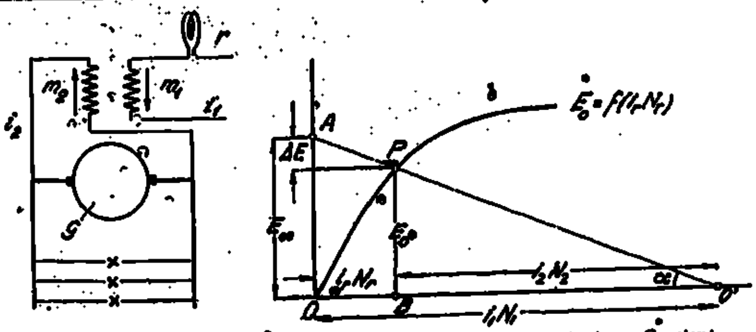


Fig. 3. First self-regulating principle: separate and counter magnetisation. Constant current in the separately excited field winding m_1.

I shall commence with the system which was first developed and the value of which depends on the circumstance that it will work entirely without regulators. The generator acts as its own regulator (fig. 1).

The generator is of particularly simple construction. The illustration shows a normal D.C. armature with a single commutator. Beside the armature is shown the stator with four wide main poles and four small auxiliary poles, the auxiliary poles only being provided with field windings. Fig. 2 shows the machine erected. The brush rocker is fixed, as opposed to most systems with which it is necessary to use movable brush rockers, which by means of friction are advanced by a pole pitch every time the direction of running of the coach is reversed. This is not necessary for the new generator. The polarity is, as for the ordinary Rosenberg machine, independent of the direction of running. The generator was originally designed for a continuous load of 24 volts and 50 amps in the lighting circuit and 33 volts and 25 amps in the battery circuit, but after testing it was found that with an improved system of coupling the voltage could be nearly doubled. The machine weighs 380 kgs but this could be materially cut down by employing a lighter design which would certainly be used if mass production were undertaken. The speed range is 450/2,700 corresponding to train speeds of 12½ to 75 miles per hour.

Before proceeding further with the description a few words must be said to explain the self-regulating principle of the generator. This is very simple. Fig. 3 shows a normal D.C. generator G with field windings m_1 and m_2. The winding m_1 is separately excited by a current i_1, the magnitude of which is maintained constant by the help of an iron wire resistance r. The winding m_2, which has a demagnetising influence, is excited by the generator voltage E_0. The field ampere turns $i_2 N_2$ are accordingly always proportional to the generator voltage; or, put differently, $E_0 = \text{const.} \cdot i_2 N_2$

Fig. 3 a shows how we are able, on the basis of the above formula, to calculate the generator voltage and the variations of it graphically. The first point O' is determined by setting up the ampere turns of the separate magnetisation $i_1 N_1$, afterwards the straight line voltage characteristic O' A is drawn in accordance with the first equation with

$$\tan \alpha = \frac{E_0}{i_2 N_2}$$

Where this line cuts the no-load characteristic, the point P is given to which the generator voltage rises.

We assume now that the no load characteristic is drawn for the lowest speed for which the generator is designed. For infinitely high speed the no-load characteristic would coincide with the ordinate axis. It will accordingly be seen at once that the generator voltage between the lowest speed and infinitely high speed only varies by

$$\Delta E = E_\infty - E_0$$

and that

$$\frac{\Delta E}{E_0} = \frac{i_r N_r}{i_2 N_2}$$

i.e. similar to the relation between the resulting ampere turns $i_r N_r$ and the demagnetising ampere turns $i_2 N_2$. If this relation is made sufficiently small the voltage will also remain sufficiently constant.

It is, however, easily seen that this system of connection gives rise to great waste of ampere turns. The relation between resulting ampere turns at the lowest speed and the total ampere turns at the highest speed is in fact

$$\frac{i_r N_r}{2\, i_1 N_1} = \frac{\frac{\Delta E}{E_0}}{2\left(1 + \frac{\Delta E}{E_0}\right)}$$

accordingly for $\frac{\Delta E}{E_0} = 0.1$

$$\frac{i_r N_r}{\Sigma i N} = \frac{0.1}{2.2} = 0.0455$$

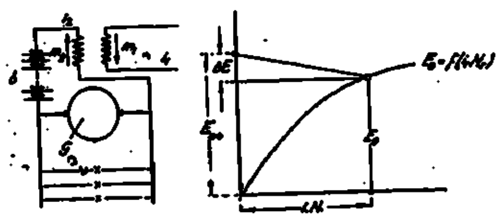


Fig. 4. Second self-regulating principle: separate and counter magnetisation. Constant counter E.M.F. in series with the demagnetising field m_2.

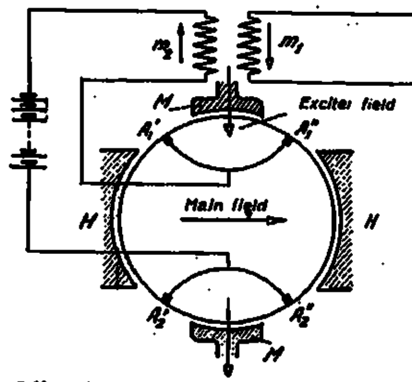


Fig. 5. Self-regulating principle of new train lighting generator.

The copper in the field winding is accordingly only utilised to the extent of approximately $4^1/_3$ %.

In this respect the system of connections shown by fig. 4 is more economical. This differs from the former by the introduction of an auxiliary battery b, the e.m.f. of which is equal to the generator voltage E_0 at the lowest speed but opposed to it in polarity. At the lowest speed accordingly the terminal voltage and current of the demagnetising winding is equal to zero and the ampere turns in the main field winding m_1 give rise at the same time to the resulting ampere turns i_rN_r. If now the speed rises, the generator charges the battery through the demagnetising winding and at infinite speed the generator voltage would rise so high that the demagnetising ampere turns $i_{max.}N_2$ just neutralised the constant ampere turns i_1N_1. The relation between the resulting ampere turns at the lowest speed and the total ampere turns at the highest speed is accordingly 50 % and this can be tolerated. On the other side, however, the voltage increase ΔE between the lowest and highest speed cannot be maintained sufficiently small without heavy cost and losses. Assume, for example, that ΔE is not to rise more than 10 % of the lowest generator voltage plus the necessary rise which the battery voltage undergoes during charging. Assuming further that the demagnetising winding takes as little as $2^1/_2$ % of the useful power, the maximum charging current at the highest speed would then reach nearly 25 % of the useful full load current and apart from this considerable loss of energy it would be necessary to make use of an auxiliary battery capable of taking a charging current up to a maximum of 25 % of the full load current. Such a thing could never be considered.

We come accordingly to the conclusion that the connections shown in figs. 3 and 4 are worthy of consideration but not for a full size machine, but eventually for the circuit of a smaller exciter machine. The main generator should accordingly be provided with an exciter, the field of which could be regulated in accordance with the principles described above.

But one could not seriously propose to drive two machines from the coach axle instead of one. Such a system would be immediately condemned. The only practical possibility for designing a generator with the self-regulation described above is accordingly to combine the exciter machine in the generator itself and to weld the two together as it were to an organic whole. This has now been successfully accomplished and I accordingly come to the actual construction of the generator.

In fig. 5 the generator is drawn showing the two auxiliary poles M-M and two main poles H-H. In each of the 4 pole spaces is placed a brush. The brushes are arranged in pairs and so connected together that the connecting leads short circuit the voltage which is generated by rotation in the field of the auxiliary poles. The auxiliary poles are in fact nothing but the main poles of the exciter which has been suppressed. This is indicated among other things by the fact that these poles carry the field windings m_1 and m_2 previously referred to which oppose one another. It may be asked "what has become of the exciter armature"? This is there alright and is formed by the sections of the winding A_1' A_1'' and A_2' A_2''. Here a rotation voltage is generated and this is the terminal voltage of the suppressed exciter. If these brush groups are short circuited a current is produced in the armature of the so called exciter but also in the main field winding of the lighting generator. How is this brought about? The ampere turns in the short circuited winding sections excite a

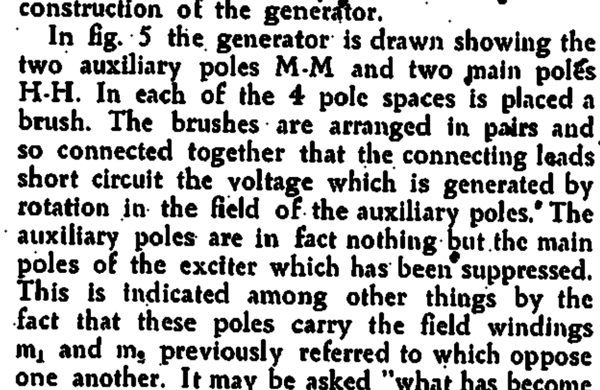


Fig. 6. Distribution of main field and position of brushes.

field through the main poles H-H. There is accordingly no room for doubt that the armature of the exciter, *i.e.* the short circuited winding sections, functions at the same time as the field winding of the main machine.

If the above combination of exciter and

generator in the same machine has been grasped everything else will be clear. If H-H are the main poles of the generator then naturally the winding sections A_1' A_2', also A_1'' A_2'' form the armature winding of the generator. Here accordingly the lighting voltage E_0 is generated and this is connected to the demagnetising winding m_2 of the exciter, either direct or through the auxiliary battery mentioned earlier. We accordingly obtain in this way precisely the same self-regulation with constant voltage but this is no longer effected in an uneconomical way but with small power and losses. In the first machine to be completed for test purposes, and which was found to be unnecessarily large, the separate field is supplied by the main battery with approximately 6 watts, the demagnetising winding m_2 absorbed a maximum of 0.53 amps at 1.3 volts, thus 0.7 watts. There can accordingly no longer be any question of waste of energy in the field. In addition the terminal voltages of the auxiliary battery and generator never show a larger difference than 1.3 volts. As an auxiliary battery a small Jungner battery is employed of 14 to 15 cells and having a capacity of 9 ampere hours. The normal charging current is given as 2.25 amps. Although the battery is thus exceedingly small it is used for an even smaller output than it is capable of, the mean current charge being only one sixth of the normal charge current.

I wish especially to point out that this auxiliary battery should not be regarded as a weak point. In the first place it is very small and in the second it is never discharged. It is subjected to charging alone and this by a current which is so small that the battery can withstand it for a sufficient time without any damage. That this is the case is vouched for by the Jungner Accumulator Company. The auxiliary battery requires no other attention than is given to the main battery, namely filling with distilled water about every month. I repeat that discharge never occurs. Even when the coach is not in service self discharge cannot take place, which will be shown later. (Fig. 8).

It has now been made clear that we have a generator with exciter eliminated and without any regulator which will maintain a constant voltage. It will, however, give only a single voltage, the lighting voltage. It remains to be found how the additional 30 % for charging purposes is to be secured. Happily, the solution of this question does not give rise to any difficulty. The machine is in fact only fully utilised when this additional possibility is made use of. Fig. 6 shows the division of the main field of the generator which, as pointed out earlier, is

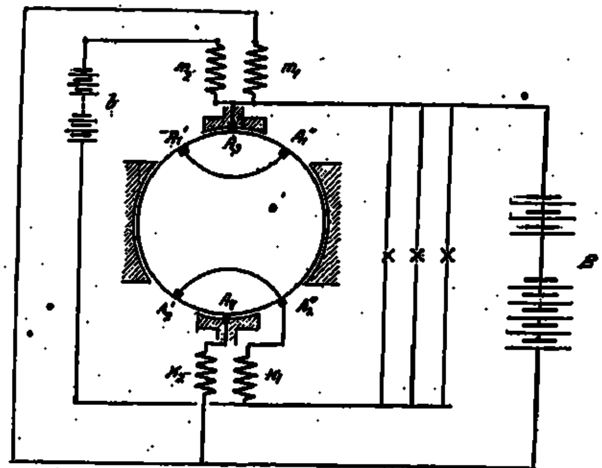


Fig. 7. Diagram of connections for new train lighting system.

produced by the ampere turns in the short circuited winding sections under the auxiliary poles. Of this field so far only the surface under the main poles has been employed. If two brushes A_3 A_4 are introduced under the centres of the main poles, the pressure between them is greater than the lighting voltage and in the same proportion as the total flux is greater than the flux in the main poles. It is easy to calculate the arc of the auxiliary poles in proportion to that of the main poles in order to obtain the desired proportion between the charging voltage and the lighting voltage. At no load this proportion is constant, and as the lighting voltage of the generator in accordance with the self-regulating principle is as nearly as possible maintained constant, the charging voltage is also, practically speaking, independent of the speed.

In order to obtain equally favourable conditions when charging, the armature reaction must be prevented from affecting the field of the auxiliary poles. This is achieved by using two compensating windings k_1 k_2 round the auxiliary poles of which one is traversed by the lighting current and the other by the charging current of the lighting battery. The auxiliary poles carry accordingly four windings m_1 m_2, k_1 and k_2 which are insulated from one another but combined to form a single coil as shown in fig. 1. We have now considered fully the scheme shown in fig. 7. The connections have been simplified by the brush A_3 being used at the same time as a terminal for both lighting and charging voltages. The separate excitation is supplied by the lighting battery and the demagnetisation by the lighting voltage minus the counter voltage of the auxiliary battery. Although this scheme of connections is so simple it contains everything that is required

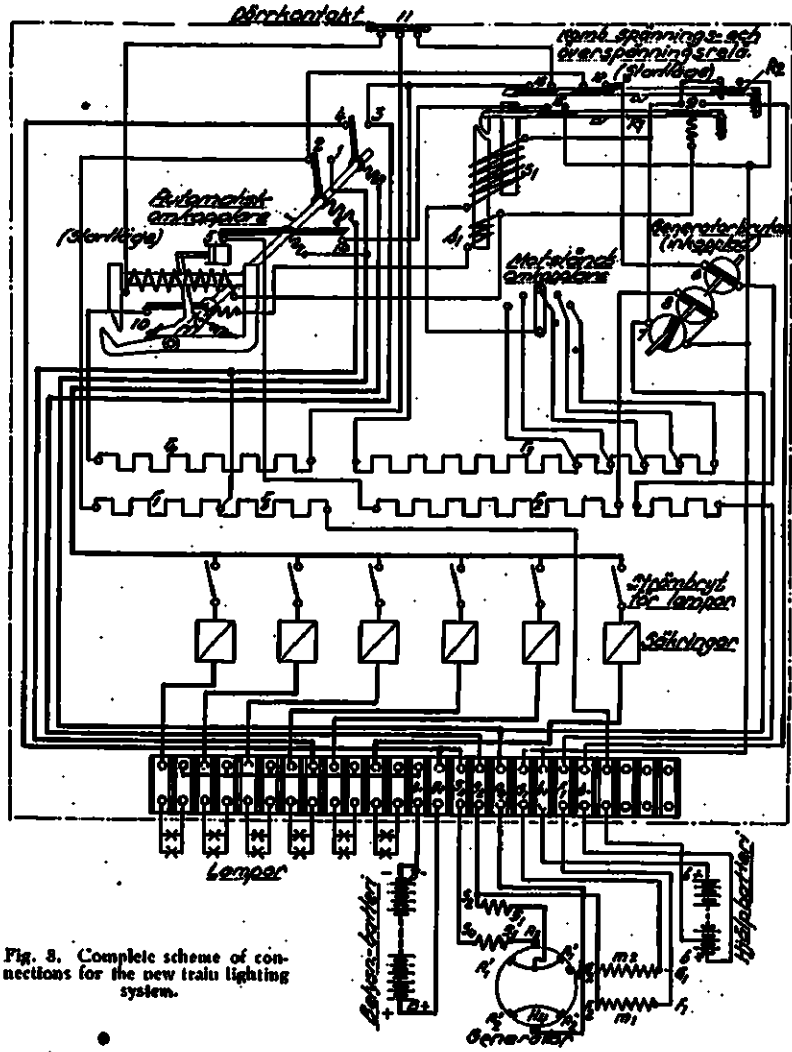


Fig. 8. Complete scheme of connections for the new train lighting system.

Dörrkontakt = Door contact. Komb. spännings- och överspänningsrelä (Startläge) = Combined voltage and excess voltage relay (starting position). Automatisk omkopplare (startläge) = Automatic changeover switch (starting position). Generatorbrytare (inkopplad) = Generator circuit breaker (closed). Motståndsomkopplare = Resistance switch. Strömbryt. för lampor = Lamp switches. Säkringar = Fuses. Lampor = Lamps. Belysn.-batteri = Lighting battery. Hjälpbatteri = Auxiliary battery.

for a first class modern system excluding change-over devices and switches.

I will deal here with an objection which is sure to arise at once, namely that the advantages of the system are counter-balanced by the use of an unsatisfactorily large number of brushes. It is easy to correct this impression.

In the first place when brushes are spoken of, or rather brush contact surfaces, this should not be confused with "brush positions". The new generator has 6 brush positions for each pair of poles while a normal D.C. machine has 2. From this, however, it does not follow that the new machine has three times as many brushes as the old.

A correct comparison may be made in the following manner. For a normal train lighting generator a brush contact surface is required in a special case for a total of 75 amps. namely 50 amps. lighting current and 25 amps. charging current. In the new machine a field current circulates in addition through the short circuited sets of brushes which, at the lowest speed, reaches approximately 50 amps. The necessary brush contact surface is accordingly in the proportion of 75 to 125 or 1 to 1.66 if the generator is to be driven continuously at the lowest train speed ($12^1/_2$ miles per hour).

Before describing the apparatus equipment which is much less than for all other train lighting systems a short description of the working characteristics of the system will be welcome.

In this respect the greatest weight must be laid upon the good commutation of the generator. The compensating windings suppress the armature reaction in the same way as commutator windings do on ordinary interpole machines and the small excess field between the interpoles reduces or suppresses reactance voltages. The fact that the brush rocker is fixed is also a great advantage from the point of view of commutation and reliability.

In addition the system works with good efficiency. Neither in the lamp circuit nor in the battery circuit are series resistances used. All unnecessary energy losses are accordingly wiped out.

The fact that the self-regulating arrangement will work without trouble will be clear to anyone who has understood the simple principle. The lighting voltage is accordingly, practically speaking, independent of the number of lamps alight, the temperature of the windings, the brush resistance and the condition of the battery as regards charge. Self-regulation can easily be obtained within wide limits, for example for train speeds between $12^1/_2$ and 70 miles per hour.

The excellent working characteristics of the generator are also of value to the battery. The battery delivers lighting current only as long as the train speed is below a certain limit (*e.g.* $12^1/_2$ miles per hour). As soon as this speed is exceeded the generator is automatically con-

nected to the lighting and battery circuits and charging begins immediately. The generator and battery never supply lighting current at the same time. The size of the battery is determined accordingly only by consideration of the time spent in stations and the discharge current. In addition, it should be noted that the charging current of the battery varies with the number of lamps alight. The battery is accordingly always charged in correct proportion to the discharge occurring during stops in stations. The possibility of the battery being damaged by overcharging is eliminated as the highest charging voltage of the generator can be prescribed as necessary.

Fig. 9. Motor regulator.

So much for the practical characteristics of the system.

I should now give a detailed description of the connection diagram shown in fig. 8 but this will be made very short. In this diagram there is in fact very little which is really characteristic of the new system. An automatic changeover switch is of course always required and accuracy is desirable as regards opening and closing between predetermined voltage limits so that it is naturally best to operate this changeover switch through a voltage relay. Since it is more economical to make a small relay insensitive to temperature variations, by the use of a constant series resistance, and yet to have it exceedingly sensitive to voltage variations, this is done rather than construct a large changeover switch on the same principle. But it is particularly characteristic of the new system that the apparatus used is exceedingly robust. The apparatus switchcase is not a wonderful and involved piece of clockwork, but the changeover switch is a heavy current apparatus which can break a very considerable overload current without damage. There are few train lighting systems with such robust apparatus equipment and this has been made possible within the small space available due to the fact that no regulators or finely divided field resistances or substitutional resistances for the lamps and battery have to be embodied.

In this equipment which constitutes a trial order for the Bergslags Railway, Sweden, we have combined the voltage relay with an excess voltage relay which breaks the separate excitation m_1 and opens the changeover switch if the self-regulation ceases. All train lighting generators work at a high speed with a weak field. If this weakening of the field should fail for any reason (in the new system it is only possible for a break to occur in the demagnetising field), the lamps would be burnt out without the inclusion of the excess voltage relay. The voltage and excess voltage relay have the same operating coil and different armatures. The introduction of the excess voltage relay is in this way made a very cheap safety device.

I need scarcely say that the whole system is always ready for service. The small battery is always kept fully charged by the main battery, which always allows a minimum current of about 0.05 amps to pass and which the main battery can deliver for approximately half a year. The guard or conductor has nothing else to do but to turn a switch, which is known as the generator switch, when the system is to put in action, at any speed of the train.

I come now to the system devised by Mr Akerman. This can be dealt with more shortly, due to the fact that the system employs the same self-regulating principle although in an entirely different and very ingenious manner. In place of a special and non standard generator an automatic rapid acting regulator is introduced in the generator field circuit. Without exaggera-

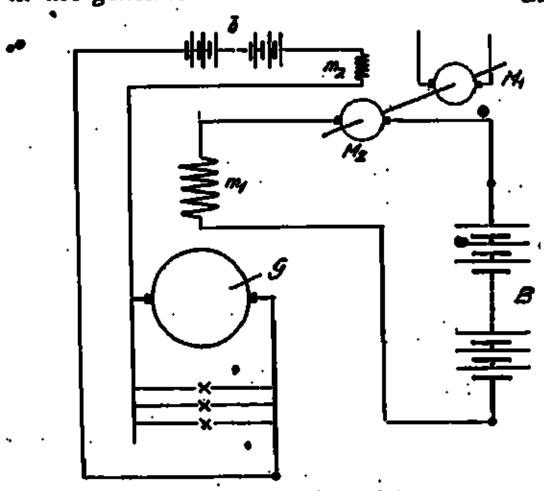


Fig. 10. Preliminary scheme of connections.

tion I think it may be said that this regulator is the most robust and simple of all regulators designed for train lighting and acts as rapidly as the best in this respect. The curious part is that it is an old acquaintance and looks like a common D.C. motor of very small size. It is in fact nothing else (fig. 9). The principle of

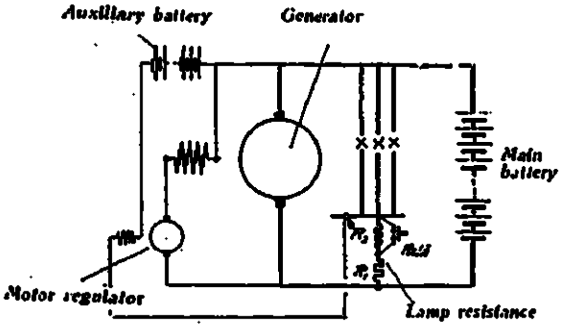


Fig. 11. Definite scheme of connections.

regulation is surprisingly simple as in the case of all inventions which are able to establish themselves in practice. The manner in which I am about to explain the action of the motor does not perhaps correspond precisely with Mr Akerman's train of thought when he produced the idea, but I have chosen it on account of simplicity. Fig. 10 shows a unit of three machines, namely the lighting generator G and the exciter unit M_1 M_2. We can at the commencement assume that M_1 runs as a motor and drives the exciter M_2. The armature of this is in series with the main field of the lighting generator m_1 which is supplied by the lighting battery B. If the field winding of the exciter m_2 has current passing through it the exciter will then generate an auxiliary voltage strengthening or weakening as the case may be and thus altering the terminal voltage of the main generator. We see now, however, from fig. 10 that the field m_2 is excited in exactly the same manner as the demagnetising winding in the former system, namely by means of the voltage difference between the generator voltage and the counter e.m.f. of a small auxiliary battery. m_2 further is designed in the same manner as the demagnetising winding in the system previously described, *i.e.* if the generator voltage increases from the lowest speed to the highest speed by about 1 volt the exciter countervoltage would completely neutralise the voltage of the lighting battery. The main field of the generator would then have no current flowing in it. It is clear that under such conditions the generator voltage can never rise higher than about 1 volt above the charging voltage of the small auxiliary battery precisely as was the case in the former system. Regulation will, it follows, always function with certainty. But it may now be objected it is equally certain that this self-regulation will only be paid for at the expense of a separate small set composed of an exciter and driving motor. Must the scheme on this account be rejected? This is not at all the case and we come here to Mr Akerman's most important addition to the regulation problem. He saw that if the so called exciter was only used to weaken the main field of the generator it would not then generate but, on the contrary, absorb energy. It runs accordingly, not as a generator but as a motor and the driving motor M_1 which is never called upon to run as a

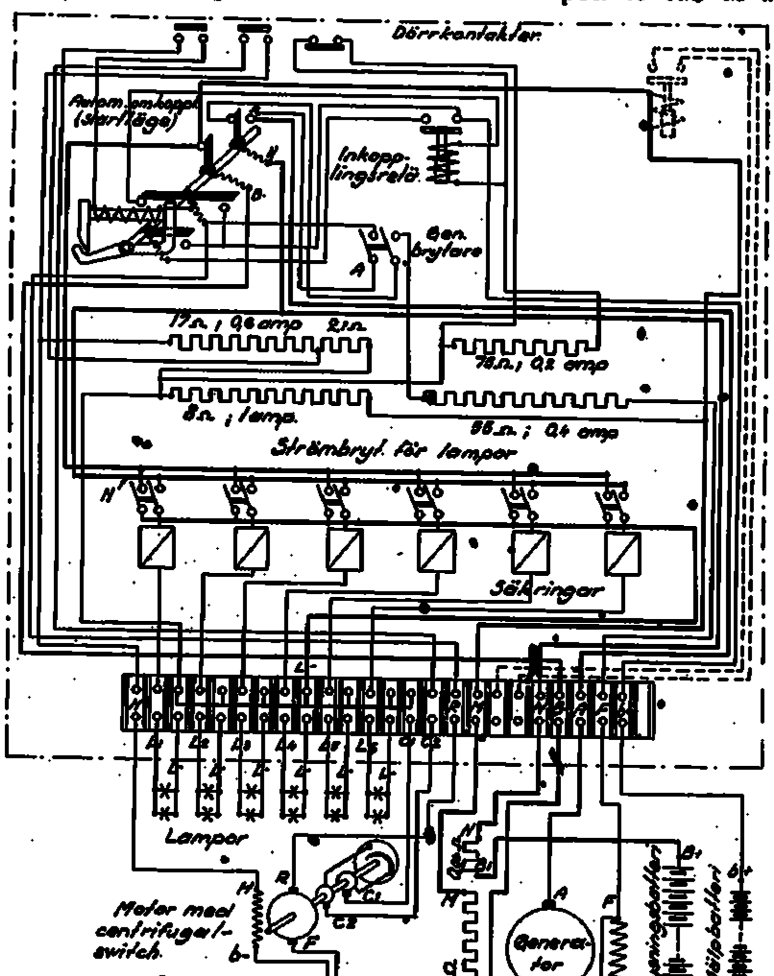


Fig. 12. Complete scheme of connections for Ing. Akerman new train lighting system.

Dörrkontakter = Door contacts. Autom. omkoppl. (startläge) = Automatic change-over switch (starting position). Inkopplingsrelä = Contact making relay. Gen. brytare = Generator switch. Strömbryt. för lampor = Lamp switches. Säkringar = Fuses. Lampor = Lamps. Motor med centrifugalswitch = Motor with centrifugal switch. Belysningsbatteri = Lighting battery. Hjälpbatteri = Auxiliary battery.

motor is quite superfluous and can be eliminated. If this is done we have reached the complete arrangement of Akerman's train lighting system. Subsequently M_2 will accordingly denote the motor regulator and not an exciter.

The function of the motor regulator is accordingly to absorb the same energy which in the case of resistance regulation would be dissipated in the series resistance. This amount of power is so small that the internal losses in the motor regulator will often be sufficient *i.e.* the highest input to the regulator is not greater than can be dissipated at the highest allowable speed of the regulator by the no-load losses. Should this power be too great in certain cases there is nothing to prevent the motor regulator being braked by fitting a small fan wheel in order to limit the highest speed of the regulator.

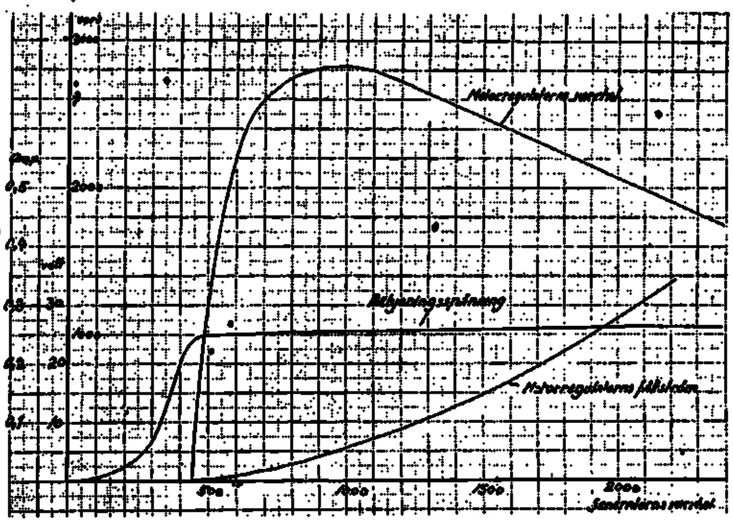


Fig. 13.

Varv = r.p.m. Motorregulatorns varvtal = Speed of motor regulator. Belysningsspänning = Lighting voltage. Motorregulatorns fältström = Motor regulator field current. Generatorns varvtal = Generator speed r.p.m.

The speed of the motor regulator is not constant but dependent on the energy to be dissipated. From this, however, the conclusion must not be drawn that regulation is affected in any way by the flywheel effect of the rotating machine. This is in fact not at all the case. If, for example, the train speed is altered so that the regulator must dissipate more energy, this happens immediately, after a minute change in lighting voltage, due to the acceleration, and this increased power consumption by acceleration continues until the increase in the no-load losses exactly corresponds to the necessary increase in power consumption. The flywheel effect of the rotating parts will not accordingly affect the speed of regulation in any way. This is only limited by the time constants in the field circuit which are very small with such a small machine as is here in question. If we compare the stability and reliability of the regulator with the corresponding characteristics of other regulators commonly in use it appears to me that no question of any competition will arise. The present system marks a definite step forward both in the direction of simplicity and reliability.

I have spoken of the Akerman "system". But a regulator does not comprise a system which is clear from the fact that a large number of well known systems can make use of the new regulator with considerable advantage. But Akerman has introduced this regulator in connection with an equipment which embodies a sufficient number of improvements to warrant our regarding it as a new system. The first improvement concerns the regulation of the battery charging current. As in the case of most systems which employ a standard machine as a generator use is also made here of a series resistance R_1 in the lamp circuit (fig. 11). This resistance naturally does not affect the lamp voltage which is kept constant by the regulator. Instead, the lamp resistance raises the battery charging voltage above the lighting voltage and this increase is equal to the voltage drop in the resistance. As this voltage drop is proportional to the lighting current the battery charging voltage reaches its highest value when all lamps are alight. In order that charging voltage may be sufficiently effective even when only a few lamps are alight, a relay is used which with a low lighting current serves to connect a substitutional resistance R_2 in one or two steps. This arrangement was chosen on account of its simplicity. There are naturally a large number of more exact solutions but perhaps none more simple which are equally reliable in operation.

Another detail of even greater importance is the use of two separate devices for connecting and disconnecting the lighting generator (fig. 12). When the train starts and the generator voltage rises a voltage relay at about 30 volts connects in circuit the field of the motor regulator. The motor accelerates and when it has reached about 500 r.p.m. closes the operating magnet of the contact breaker by a centrifugal switch. This closes and the system is then in working order as regards all parts. When the train speed decreases the speed of the motor regulator also

falls and at a given minimum train speed the centrifugal switch breaks the field coil of the contact breaker. The whole system then returns to the starting position. It is accordingly the generator *voltage* reached which determines the closing but the *train speed* which determines the opening. In this manner it is possible to obtain practically the same generator voltage for closing and opening. Flickering of the lamps when changing over from generator to battery lighting or vice versa is thereby effectively reduced. It would be in fact entirely eliminated if the battery always had precisely the same discharge voltage. It may be objected here that the connection of the generator must in all cases be made at a higher train speed than the disconnection since the closing of the centrifugal switch naturally takes place at a higher speed than opening. This is, of course, correct. If, however, we now examine fig. 13, which shows the speed of the regulator as a function of the speed of the train, we see that the speed of the train only alters by 10 % while the speed of the motor regulator varies in the ratio of 1 to 5. Even if the sensitivity of the centrifugal switch were extremely bad and variable still opening would only take place at a predetermined train speed which lies a little below the closing speed.

Finally, we are quite prepared to meet the objection that all centrifugal switches of known design give trouble. Any new development of centrifugal switch is likely to be more troublesome still. But just on this account it is so important in case of the system in question that great insensitivity and possible variations are of so small moment. In addition the centrifugal switch which is actually used is of the greatest simplicity and on continuous service it has been found to work so satisfactorily that we place the greatest possible confidence in it. We have been able to instal Akerman's system on one of the coaches of the Bergslags Railway and in a very short time we shall be in a position to give some practical details regarding its working.

Finally I must mention that Asea also constructs a system with carbon resistance of the so called U.S.L. connection. The system cannot be regarded as new but the construction has been so well revised, and so many new details have been introduced that it can almost be regarded as a renaissance of the well known old system. The Swedish State Railways have ordered complete equipments for 25 coaches and these are almost ready for delivery.

L. Dreyfus.

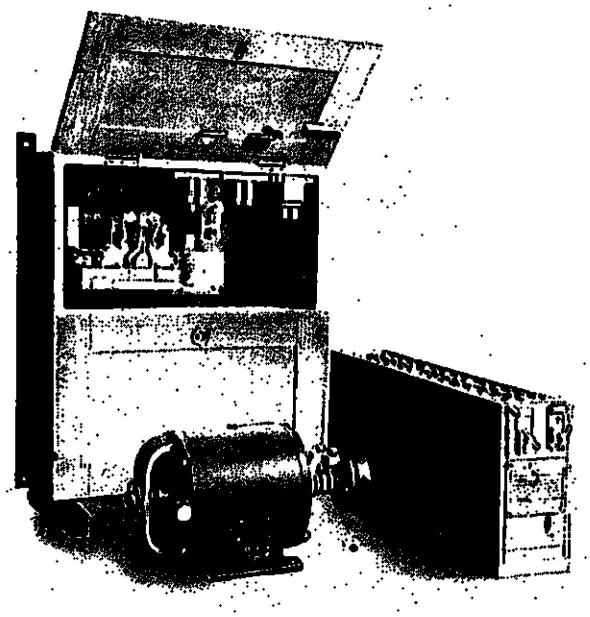
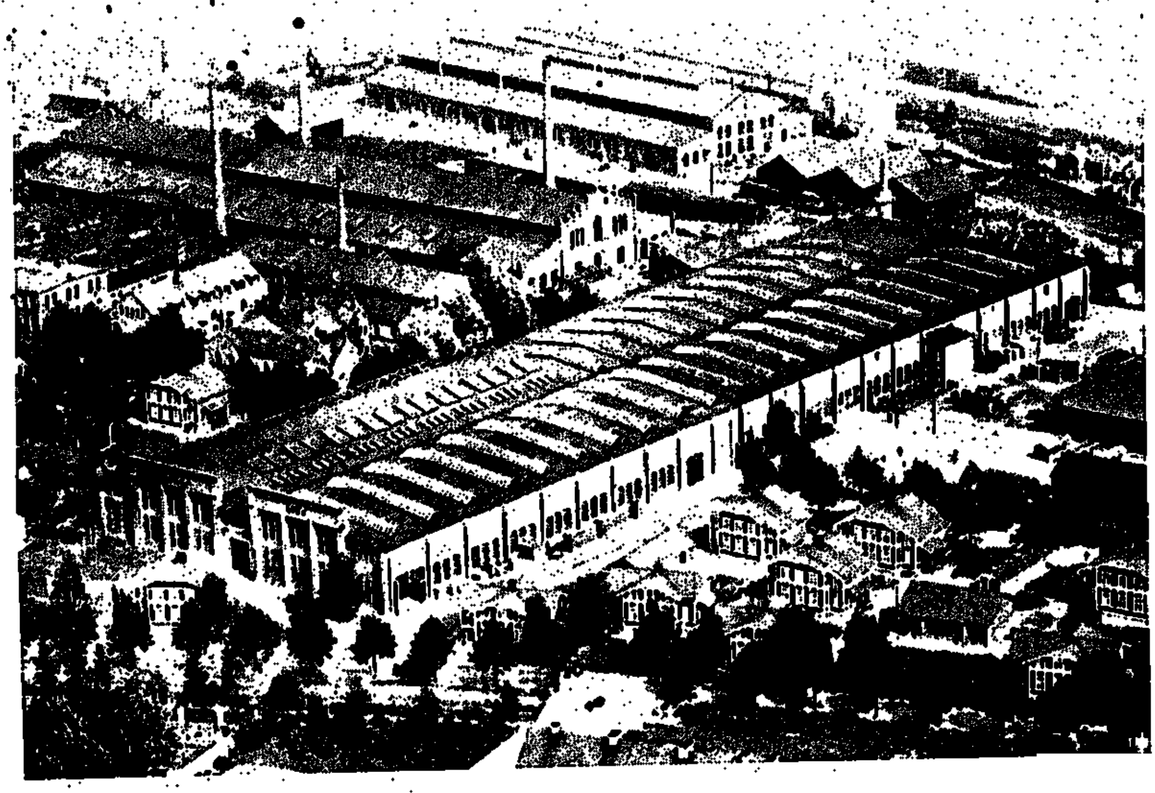


Fig. 14. Apparatus equipment for Akerman train lighting system.

FRONT PAGE.

INTERIOR OF ASEA'S FACTORY FOR LARGE MACHINES AND SHOWING THE LARGEST THREE-PHASE GENERATOR IN EUROPE.

We have this time chosen for our front page a photograph showing an interior view of Asea's factory for large rotating machinery, known as the Emaus Works situated at the east end of Vesteras. The photograph is taken in the last bay built in 1925 and shows in the foreground among other parts two rotors for the large generators which Asea built for the Finnish Government Power Station, Imatra. Behind the rotors the travelling crane is lifting the stator from the large testing pit, the edge and hand railing of which can be partly seen on the right. Further back among other machines can be seen additional parts for the Imatra order which included three vertical three-phase generators each for a continuous output of 24,000 kVA at 125 r.p.m., 50 cycles, 10,000—11,000 volts and $\cos\varphi = 0.8$. An idea of the dimensions of these machines can be gathered by comparison with the size of the man standing by the hand rail of the testing pit. Having regard to output only there are to day other generators of a similar capacity and even larger in Europe — the first machine built by Asea, for instance, for 24,000 kVA was constructed about 7 years ago — but from the point of view of size the Imatra generators cannot be equalled in the Old World. The greatest diameter at the base ring is 9.5 metres, while the height of the machine from the shaft flange to the upper edge of the direct connected exciter is 8 metres. The total weight is also surprising and according to actual measurements when transporting is not less than 350 tons for a complete machine.



Large machine works.

For the manufacture of such giant machines we naturally require not only considerable workshop space but also exceedingly large machine tools and first class lifting and transporting arrangements. Asea has from year to year continually extended and rebuilt the large machine shops so that they have always been and still remain among the largest and most powerfully equipped in Europe. The first section of the Emaus Works was built in 1899 and was then one of the largest manufacturing shops in Sweden, the floor space being 3,800 m². It has a centre bay 10 metres high, and two

somewhat lower side bays and is equipped with two 25 ton, two hoist, travelling cranes and one 10 ton, one hoist, travelling crane, all with a span of 17.3 metres and a lifting height of 6.1 metres. Also, for the side bays there are two 10 ton, single hoist travelling cranes with 6.45 metres span and 4.8 metres lifting height. The standard railway track from the works sidings is, of course, carried into the works so that waggons can be loaded from the travelling cranes and there are in addition the ordinary transport rails on the floor which is also largely covered with steel sections and plates to which both machine parts, on which work is to be done, and machine tools can be fixed down. For testing the large machines which were from the commencement manufactured here, a separate part of the shop was provided with two testing pits with suitable machinery equipment. The power supply was, however, so soon fully utilised that testing of large machines had to be carried out during the night and at other times when the shops did not require power for driving. The difficulties reached a maximum with the testing of the first four 11,000 kVA generators for the Swedish State Power Station at Trollhattan.

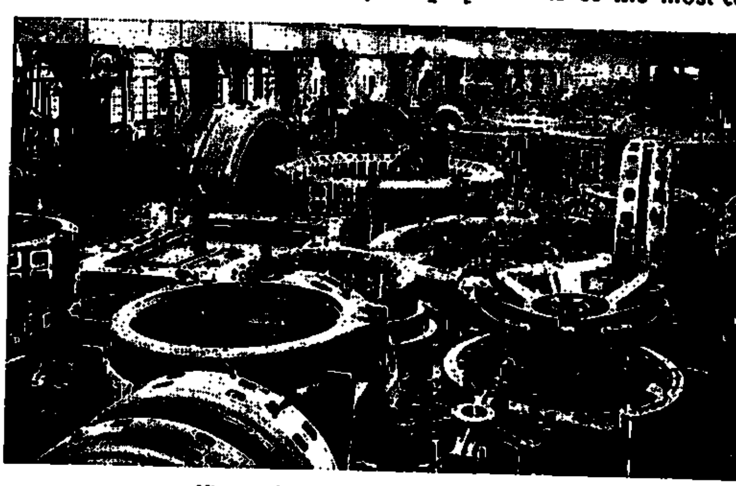
At this time also the available space became insufficient and accordingly in 1909 the shop was extended by the addition of a parallel bay with a floor space of something over 3,400 m². This bay was made 3.4 metres higher than the centre bay of the first section and it was equipped with two considerably heavier travelling cranes. These have three blocks, the same span as those in the first shop but with a lifting height of 7.1 metres and are capable of lifting 50 tons.

In spite of the extended works it was again in a short time found difficult to carry out work in a satisfactory manner on machinery which was always increasing in size. Accordingly in 1913 a further shop was built lengthening the oldest shop about 80 metres at its western end. The new shop was also made in three bays with the same width as the first but with the centre bay something more than 5 metres higher and the side bays increased in height by the same amount. The available floor space was something over 3,600 m². The crane equipment was also strengthened by a 50 ton travelling crane with three hoists and a 10 ton crane with one hoist, both for a lifting height of 7.1 metres, these being placed in the centre bay while a 15 ton travelling crane with one hoist and a lifting height of 4.8 metres was erected in one of the side bays.

The necessity for this extension can be gathered from the illustration below which shows how the space is almost entirely covered, this photograph being taken only a few years after the extension was opened. By transferring some of the manufactures to the Asea shops in Ludvika a little improvement was effected but the space gained was soon utilised again.

In 1925 accordingly still another extension was put in hand and the illustration on the first page shows a part of it which is an extension to the shop opened in 1909 and alongside the extension of 1913. The floor space of the Factory has been increased in this way by about 2,100 m². The height and the span of the travelling crane is the same as for the 1909 shop which is seen in the background but the new crane, provided with three hoists is designed for a load of not less than 125 tons.

The available floor space of the four Emaus shops accordingly, at present, reaches practically 13,000 m². To this should be added a number of separate factory buildings such as the plate shop, the forge *etc.* amounting to some 1,000 m² additional floor space so that the real floor area is about 14,000 m². All parts are equipped with the most modern electric lighting arrangements, heating radiators and mains for electric power, gas, compressed air, water and ventilation while the fixed and portable machine tool equipment is of the most complete and modern design enabling rapid precision work to be carried out even on the largest machines.



View in the oldest bay of the Emaus Works.

The gigantic machines turned out in the Emaus shops are, like all other machines of Asea's manufacture, subjected to detailed tests before delivery and a well equipped test room is provided to ensure that this is rapidly

and carefully carried out. The test room now occupies most of the eastern part of the Works erected in 1899 and 1909. The test room machinery is housed in the oldest side bay and in the main bay are two test pits while in the 1909 bay alongside two test pits are also provided, although of considerably larger dimensions. In this bay is also a large overspeed pit in which the rotors of all large machines are tested at runaway speed in completely finished condition, which corresponds to the arrangement in the older building consisting of an overspeed chamber arranged in the long wall for testing smaller horizontal machines. These testing facilities were not sufficiently large for the big vertical generators and in the 1925 extension a test pit has been made 12 metres in diameter and 4.6 metres deep. In this the largest machine so far constructed can be tested under exactly the same conditions as exist when they are finally erected in power stations. Air for ventilation is drawn in through a duct under the floor. The machines are subjected to complete measurement of losses and heat run partly at no load running as a motor with full voltage and minimum current and partly running as a motor with full current and reduced voltage. The last named test is a substitute for the common short circuit test but requires no driving motor. The machine is started by the slip method from the test room generator and no other driving motor is provided.

ASEA SYSTEM OF DIFFERENTIAL PROTECTION FOR GENERATORS.

It has for some time been common to protect large generators from damage, due to internal faults, by the employment of some differential protecting system. The most common fault which occurs in the windings of a generator has the character of a leakage to iron. The sensitivity of the protective device thus must be considerable since it is usual to earth the neutral point of a generator through a resistance which limits the earth current. This resistance which, for large generators, must be of considerable size, can accordingly be designed for smaller currents the more sensitive is the device. The sensitivity of a differential protective device is limited in the first place by the load characteristic of the current transformer employed and the energy consumption of the relay. The maximum sensitivity which should be obtainable from these considerations is not however, obtained with the common system of protection shown in fig. 1. An inconsiderable difference in impedance between the leads on opposite sides of the relay gives rise to an inequality in the loading of the current transformers and the difference in magnetising current passing through the relay may for this reason be so great that release may occur when it is not desired. In addition, it is usually impossible to ensure that the magnetic characteristics of the two current transformers will be exactly the same and the unpreventable inequality may also cause undesired tripping to take place on short circuits.

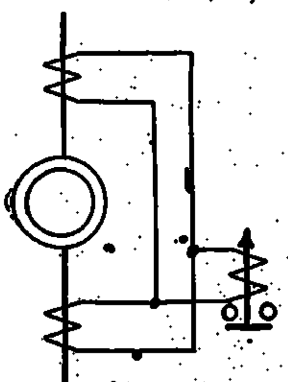


Fig. 1.

With regard to the risk of this nuisance caused by undesired tripping it has been thought necessary to use specially balanced current transformers for differential protection and also to balance carefully the impedance of the conductors. In spite of this the sensitivity obtained in general does not exceed about 10 % of normal current which, having regard to the desirable margin of safety in the case of a fault in the neighbourhood of the neutral point of the generator, would necessitate a resistance to carry 30 to 40 % of the normal current.

A number of different methods for overcoming the risk of undesired tripping of the main switch have been devised but have all necessitated current transformers of special construction which in generel cannot be used for any other purpose than that of the actual protective device.

The Asea system of protection now to be described makes use of current transformers which are, practically speaking, fully standard and which in addition may be loaded with relays and instruments to such an extent that additional current transformers are only required in very exceptional circumstances.

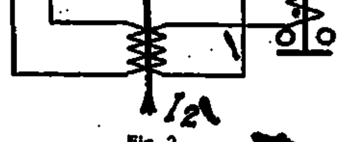


Fig. 2.

The principle of the device is indicated in fig. 2. As will be seen each of the current transformers has two secondary windings namely one for the overload relays and instruments

and one for the differential protection. The instrument load windings are series connected so that they assist one another and the differential windings are connected so as to oppose one another. If the currents in the two windings are i and i' respectively and the primary currents are I_1 and I_2, then:

$$i + i' = I_1$$

$$i - i' = I_2$$

from which

$$i = \frac{1}{2}(I_1 + I_2)$$

$$i' = \frac{1}{2}(I_1 - I_2)$$

The differential windings accordingly carry no current as long as there is no fault on the generator *i.e.* $I_1 = I_2$ and the instrument windings carry the whole current. Any load due to instruments or relays will naturally be equally divided between the two current transformers and all unintentional releasing is excluded as long as the current transformers are exactly the same.

The damaging effect of differences in the current transformers is eliminated in a way which can best be understood by a reference to fig. 3. The two curves are assumed to be magnetising curves for two current transformers having slightly different characteristics. If the impedance of the relay were zero, *i.e.* if the differential windings were short circuited the voltage, and thus the flux density, would be the same for both transformers. For this, however, different magnetising currents i_1 and i_2 would be required and since the instrument and relay windings for both transformers carry the same current, a current of the value $\frac{1}{2}(i_1 - i_2)$ must traverse the differential winding and the relay. In the case of high excitation, this current may increase almost without limit and the only means of overcoming it would be to reduce the flux density to the necessary extent by bringing the load on the instrument windings down to a sufficiently low value. This method, however, meets with practical difficulties, as the phenomena occurring on short circuits give rise to unsymmetrical currents, causing densities which are high and very difficult to calculate.

Accordingly, if the differential winding is open the magnetising currents for the two transformers will be the same and the voltages will differ from one another by an amount e corresponding to the induction $B_1 - B_2$. This difference, if the core and transformer design is carefully done, can be kept within quite low limits; the value for $B_1 - B_2 = 1000$ need never be exceeded in the case of transformers of Asea

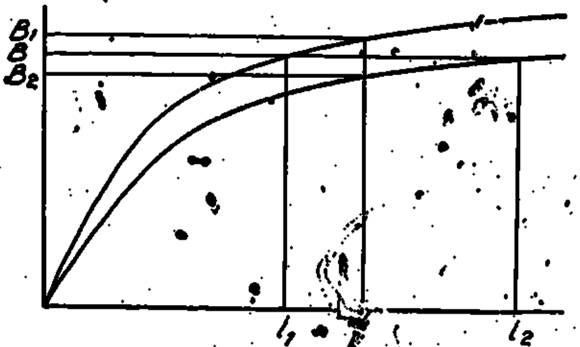


Fig. 3.

manufacture with the quality of transformer sheet normally used for current transformers. If now the circuit is closed through a relay having a certain impedance z the current will clearly never exceed the value e/z and it is a simple matter to design the relay and the differential windings in such a manner that this current is less than the tripping current required by the relay. The Asea differential protective devices are designed in such a way for a value of $B_1 - B_2 = 2000$, thus considerably above the value found by experience as above. The factor of safety against undesired tripping is accordingly so great that even a break in the instrument load does not give rise to any trouble.

The relay has such a high impedance that the magnetising current of the current transformers is considerably greater than the effective relay current. On the other hand the relay is wound for a very low current and the sensitivity reached therefore is very near the highest value obtainable with the type of relay and current transformer which is used, viewed altogether, apart from the question of the risk of undesired action.

The differential winding contains only a few turns and can accordingly be added to an ordinary standard current transformer without encroaching too much upon the space for the ordinary instrument winding. This has a load capacity of about 100 VA in accordance with class B or C of B. E. S. A. Standards and this load is sufficient in most cases.

The relay is of the Asea type RMSS with a consumption of 0.1 VA and brings about tripping with a fault current of about 2 % of the normal full load current. It will be seen accordingly that the neutral point resistance may be safely designed for about 7.5 % of normal full load current. The tripping current depends to a considerable extent upon the magnitude of the load on the generator since the flux density and thus the permeability varies with the current. The value given corresponds to the most unfavourable condition of working which can be obtained.

I. Herlitz.

OSCILLOGRAMS.

The widely flung activities of Asea compel Mr. J. S. Edstrom, the Managing Director of the Parent Concern, to spend much of his time in travelling. He fully appreciates the advantages of rapid travel afforded by the various European air lines and is seen above, at Croydon, thanking his pilot for a pleasant journey from Amsterdam to London.

At the international Congress for the Scientific Management of Labour, which was held in Rome from the 5th to 8th September, about 1,300 representatives from Europe, Asia and Africa attended.

In Rome, those taking part in the Conference had an opportunity of visiting a number of industrial undertakings and in Turin an interesting 120-kilometres motor drive was arranged along the ancient Roman roads leading up to the Alps where several power schemes in process of development were visited.

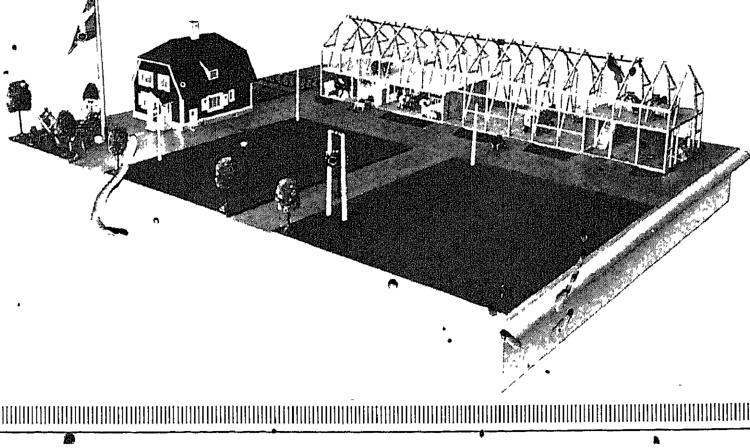
Mr. Olof Karnekull a Swedish engineer who was also present at the Congress writes in the October number of "Meddelanden från Sveriges Industriförbund": "The Swedish representatives experienced a feeling of pride when the Chief Engineer of the Station at Maen pointed out transformers recently supplied by Asea with the words "They are the best in the world"."

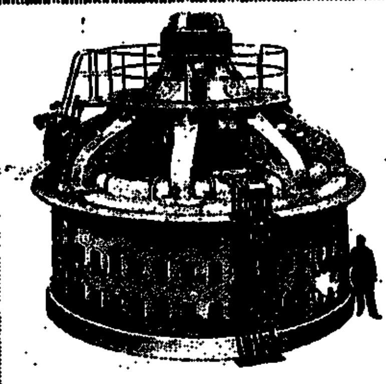
Asea, it is well known, have large Works for the manufacture of machines and transformers at Walthamstow, London. The illustration shows a large self-cooled transformer being taken along a street on the outskirts of London. Strictly speaking, the transformer is not actually being moved as it had come to a dead stop at the time and it was necessary to obtain another pair of horses in addition to the 8 shown before a fresh start could be made.

We show below a model of an electrified farm intended to demonstrate the advantages of electricity in agriculture.

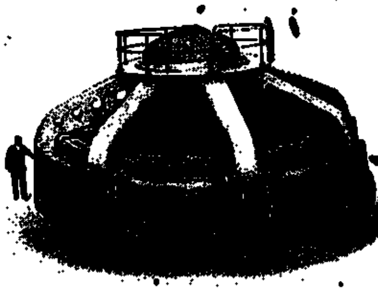
The model is to a scale of $^1/_{20}$ and represents a Swedish small holding with a two storied farm house and extensive barn.

In the foreground will be seen the pole transformer and in front of the barn a portable motor driving a threshing machine. In the loft is a chaff cutter and also a winnower. At the right hand end of the barn is a circular saw and at the left hand end a grindstone. Everything is electrified and the model gives a good impression of a modern Swedish farm with the usual machinery employed, arrangements for live stock, *etc.*

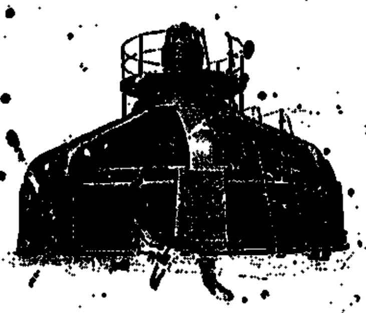




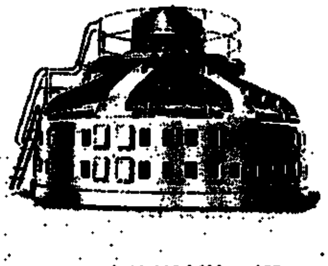
3 generators each 18,000 kVA at 214 r.p.m., 50 cycles, 11,000 volts.



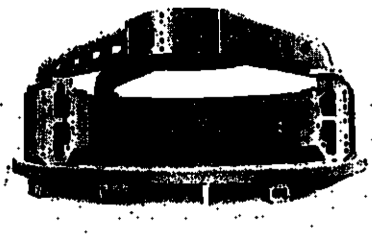
4 generators each 8,750 kVA at [illegible]5 r.p.m., 50 cycles, 11,000 volts.



3 generators each 10,000 kVA at 62[illegible] r.p.m., 25 cycles, 11,000 volts.

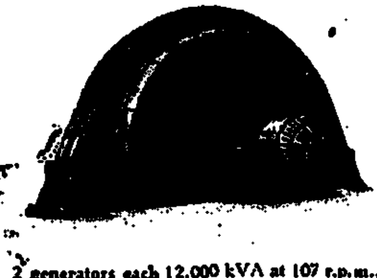


2 generators each 10,000 kVA at 187 r.p.m., 25 cycles, 11,000 volts.



3 generators each 24,000 kVA at 125 r.p.m., 50 cycles, 11,000 volts.

1 generator 24,000 kVA, 300 r.p.m., 25 cycles, 15,000 volts.



2 generators each 12,000 kVA at 107 r.p.m., 50 cycles, 7,500 volts.

The reputation of Asea generators has for long been firmly established in the markets of the world. The name is an effective guarantee of sound design and first class construction.

Asea generators are now installed in all parts of the world, their great reliability and high efficiency testifying to the quality of Asea manufacture.

The illustrations on this page show generators of both horizontal and vertical designs and in sizes from 8,750 to 24,000 kVA delivered to power stations in Sweden, Norway, Finland, Russia, Canada and New Zealand.

ASEA

VESTERAS — SWEDEN

Vesteras, Sweden. 1927. Vestmanlands Allehanda Printing Co.